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Naval Education and
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Training Manual
(TRAMAN)



Utilitiesman 1

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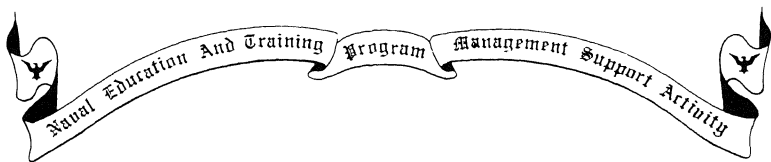
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The terms training manual (TRAMAN) and nonresident training course (NRTC) are now the terms used to describe Navy nonresident training program materials. Specifically, a TRAMAN includes a rate training manual (RTM), officer text (OT), single subject training manual (SSTM), or modular single or multiple subject training manual (MODULE); and a NRTC includes nonresident career course (NRCC), officer correspondence course (OCC), enlisted correspondence course (ECC) or combination thereof.

Although the words "he," "him," and "his" are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading this text.

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UTILITIESMAN 1

NAVEDTRA 10657-G1



*1986 Edition Prepared by
UCCM Steven G. McAllister
and UTCS Theodore C. Bockenstedt*



PREFACE

The ultimate purpose of training naval personnel is to produce a combatant Navy which can ensure victory at sea. A consequence of the quality of training given them is their superior state of readiness. Its result is a victorious Navy.

This training manual (TRAMAN), NAVEDTRA 10657-G1, and nonresident training course (NRTC) will enable Utilitiesmen first class to help themselves fulfill the requirements of their rating. They direct and coordinate efforts of individuals and crews to plan, estimate, schedule, supervise, and perform tasks involved in the installation, maintenance, and repair of plumbing, heating, steam, compressed air, air conditioning, and refrigeration systems; and maintain fuel storage and distribution systems, water treatment and distribution systems, and sewage collecting and disposal facilities.

Designed for individual study and not formal classroom instruction, the TRAMAN provides subject matter that relates directly to the occupational standards of the Utilitiesman rating. The NRTC provides a way of satisfying the requirements for completing the TRAMAN. The set of assignments in the NRTC includes learning objectives and supporting items designed to lead the student through the TRAMAN.

This TRAMAN was prepared by the Naval Education and Training Program Management Support Activity, Pensacola, Florida, for the Chief of Naval Education and Training. Technical assistance was provided by the Naval Facilities Engineering Command, Alexandria, Virginia; the Naval Construction Training Center, and the Civil Engineering Support Office, Port Hueneme, California; and the Naval Construction Training Center, Gulfport, Mississippi.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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SOURCE

American Society of Heating, Refrigerating
and Air-conditioning Engineers, Inc.

National Association of Plumbing-Heating-
Cooling Contractors

York-Shipley, Inc.

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REGULATIONS ON ENVIRONMENTAL POLLUTION AND HAZARDOUS MATERIALS

Environmental Pollution and Hazardous Waste Handling and Disposal programs have been enacted and are United States law. These programs are of immense importance and should be taken into consideration during the planning stages before beginning any new construction or rehabilitation project.

As a member of the Naval Construction Forces, United States law requires you to be constantly aware of potential environmental pollution hazards or hazardous material spills and to report them to your immediate supervisor or other senior personnel at the earliest possible time.

The following list of directives contains information on the cognizant government departments and the procedures for preventing, reporting, and correcting environmental pollution hazards and hazardous materials disposal worldwide:

- Naval Occupational Safety and Health Program Manual, OPNAVINST 5100.23B
- Environmental and Natural Resources Protection Manual, OPNAVINST 5090.1
- Domestic Wastewater Control, MIL-HDBK 1005/8

CHAPTER 1

ADMINISTRATION

Learning Objective: Identify the administrative duties and responsibilities of a petty officer first class within a Navy Construction Force occupation in relation to the Personnel Readiness Capability Program, crew member training, writing of evaluations, and maintaining reports.

The higher you ascend on the enlisted rating ladder, the more valuable you are to the Navy. This is understandable since you have more experience in your particular rating, you have probably been to several Navy schools, and your overall attitude is generally well-oriented to Navy life. In a sense, you are now better qualified and in a position to impart your knowledge and experience to the personnel under you. Your bearing, actions, and disposition are under scrutiny not only by your seniors but also by your subordinates.

Advancement brings both increased rewards and increased responsibilities. The advantages are higher pay, greater prestige, more interesting and challenging assignments, and the satisfaction of getting ahead in your chosen career. As a first class petty officer, you will have many responsibilities added to those you had as a second class petty officer. You have acquired a lot of valuable knowledge, and now it is your turn to pass on the technical know-how of your job to others.

In addition to supervising and training lower rated personnel, you must be able to perform various administrative duties, such as giving *Personnel Readiness Capability Program* interviews, maintaining reports, drafting rough evaluation reports, and organizing daily work assignments for team/crew leaders.

The type of activity to which you are assigned will determine the way you should carry out your administrative responsibilities. But the ability to plan and organize your work, to apply effective techniques of supervision, and to get along with people will help you succeed in the Navy, regardless of your assignment.

THE PERSONNEL READINESS CAPABILITY PROGRAM

The *Personnel Readiness Capability Program (PRCP)* is a management tool used throughout the active and reserve Naval Construction Force (NCF). It is a skill inventory designed to provide managers at all levels of the NCF with timely personnel information to increase their capabilities in planning, decision making, control, and in determining unit readiness.

Before PRCP was developed, personnel information was kept on an as-required basis by various members of the unit in personal notebooks, files, and records. This information was collected as management required it to determine military and construction capabilities, training requirements, logistics support, and so forth. The collection of this information was usually a time-consuming, laborious task that required a piecemeal inventory of the command's capabilities and requirements. Another way of getting this information was through the use of rough estimates. Neither way, however, produced the accuracy or rapid response desired. PRCP has helped to do so by establishing standard procedures for identifying, collecting, processing, and using this information.

The PRCP requires each participating command to gather and continuously update information on each member of the unit. Most of this information concerns skills acquired through actual job experience or through some type of training program. Other information, such as expiration of enlistment or rotation date, is required for accurate planning. This information is placed in a document called a skill update record. Each enlisted individual within an NCF

unit is required to have a skill update record, which is maintained at the company/department level. Regular updates are forwarded to the unit's PRCP manager (S-2 department).

SKILL INVENTORY

An accurate and current skill inventory is the backbone of PRCP. Without it, the reliability of any planning based on information stored in the PRCP data bank is questionable, resulting in unnecessary retraining, reduced manpower availability, or skill deficiencies. The PRCP is the management tool used to determine a unit's readiness and skill deficiencies. It is used in conjunction with the requirements established by the Commander, Construction Battalions Pacific Fleet (COMCBPAC), the Commander, Construction Battalions Atlantic Fleet (COMCB-LANT), and the Commander, Reserve Naval Construction Force (COMRNCF) which is issued in their joint instruction COMCBPAC/COMCB-LANT/COMRNCF 1500.20 (series). Additionally, these skills have been conveniently classified into the following five major categories:

1. Individual general skills (PRCP 040 - 090). These are essentially non-manipulative skills (knowledge) related to two or more ratings, such as material liaison office operation (PRCP 040), instructing (PRCP 080), and safety (PRCP 090).
2. Individual rating skills (PRCP 100 - 760). These are primarily manipulative skills associated with one of the seven Occupational Field 13 (Construction) ratings. Some examples are light-frame construction (PRCP 150) for the Builder, cable splicing (PRCP 237) for the Construction Electrician, and shore-based boiler operation (PRCP 720) for the Utilitiesman.
3. Individual special skills (PRCP 800 - 830). These are technical skills performed by personnel in several ratings, including people that are not in Occupational Field 13; for example, forklift operation (PRCP 800), ham radio operation (PRCP 804), and typing (PRCP 803).
4. Military skills (PRCP 901 - 981). These skills are further classified into three subcategories: mobilization, disaster recovery, and Seabee combat readiness. Examples are aircraft embarkation (PRCP 902); M-16 rifle use and familiarization (PRCP 953); and disaster recovery, heavy rescue (PRCP 979).
5. Crew experience skills (PRCP 1000A - 1010A). These skills are gained by working with others on specific projects. Most of these projects

are related to advanced base construction, such as observation tower (PRCP 1002A), fire fighting (PRCP 1009A), and bunker construction (PRCP 1008A).

A skill inventory has three principal steps. First, each skill is closely defined and broken down into task elements, so each person will give it the same meaning. Second, a standard procedure for obtaining the information is developed. This procedure helps to ensure that the information, regardless of where it is collected or by whom, meets certain standards of acceptability. The third and last step is the actual collection of the skill data and includes the procedures for submitting the data to the data bank.

Skill Definitions

PRCP, NAVFAC P-458, volume I, *Skill Definitions*, contains a definition for every PRCP skill identified in the *Personnel Readiness Capability Program*. Each definition has been jointly approved by COMCBPAC, COMCB-LANT, and COMRNCF (Commander, Reserve Naval Construction Force) and applies to the entire Naval Construction Force.

PRCP Standards and Guides

The skill definitions alone do not contain sufficiently detailed information to accurately classify people, nor do they provide any classification procedures. Recognizing this, the Civil Engineer Support Office (CESO) conducted special Seabee workshops where the PRCP, NAVFAC P-458, volume II, *Standards and Guides*, was developed under the guidance of CESO. This volume consists of seven separate manuals—one for each Seabee rating. The *PRCP Standards and Guides* is the principal tool used in collecting and updating skill data. By following the interviewing procedures in the *PRCP Standards and Guides*, a trained interviewer is able to classify people to a predetermined skill level with an acceptable degree of uniformity. Also, by having a thorough knowledge of the tasks required of each skill, anyone so authorized can classify others to an appropriate skill level by actually observing them perform the tasks, either in training or on the job.

Skill information obtained by interview or observation is recorded on the individual's Skill Update Record (fig. 1-1) and forwarded to the unit's S-2 department where it is recorded on the

710—Plumbing

Contents

710 Skill Definition

- .1 Skill Level 1
 - .01 Install sewage collection systems
 - .02 Install interior plumbing
 - .03 Install water distribution systems
 - .04 Install steam piping systems
 - .05 Install galley equipment
 - .06 Gas cutting and welding pipe/tube
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 - .01 Lay out piping systems
 - .02 Test newly installed piping systems
 - .03 Maintenance of interior plumbing fixtures
 - .04 Maintain water distribution systems
 - .05 Maintain galley equipment

Figure 1-2.—Title and content of the PRCP Standards and Guides.

and tasks defined in the PRCP *Standards and Guides*. Since few individuals possess the talent required to interview in all the skills of a rating, the interviewers must be mature enough to recognize their own limitations and be willing to seek assistance from individuals holding the skill being interviewed; for example, using the crane crew supervisor to assist in interviewing personnel for crane skills.

Other Interviews

Other interviews are used to classify people into the individual general and special skills, military skills, and crew experience. With few exceptions, these skills do not require an experienced interviewer. In many cases, skill levels can be assigned to individuals on the basis of their service or training record and by completed training evolutions, such as contingency construction crew training or block military training. This should be done whenever possible to cut down on interviewing time. Then, when a person is scheduled for interviewing, it will be just a matter of verification or updating.

SKILL DEFINITION

710—Plumbing

Skill Level 1:

Individual must select, use, and care for hand tools, equipment, and machines commonly used for measuring, marking, cutting, threading, and joining the following types of pipe; steel, wrought iron, copper, plastic, cast iron, cement-asbestos, concrete, and vitrified clay; and gas cut and weld pipe/tubes using methylacetylenepropadiene (MAPP) gas. He must also install plumbing systems for water, steam, air, fuel, sewage and rough-in plumbing for building; install fixtures and accessories such as bathtubs, water closets, sinks and urinals; apply insulation on steam, hot and cold water piping systems; and hook up equipment such as hot water heaters, water coolers, and galley equipment such as steam chests, coppers, dishwashing machines, ranges and ovens, both gas and oil fired.

Skill Level 2:

Skill Level 1 plus utilize drawings and specifications to determine grade, bedding, and backfilling requirements, and types of materials; to locate risers and position of sleeves in walls, floors and footings; to establish rough-in measurements; to designate the spacing of pipe supports for all types of piping systems. Also, he must read and interpret grade stake marks used in laying out trenches; utilize batter boards and grade lines; specify the location and size of thrust blocks; make service connection on transit pipe; cut machine pipe and install transit pipe utilizing lathe; perform hydrostatic and gravity tests on newly installed piping systems; treat and test water in new distribution systems; be able to operate drilling tapping machines; maintain all types of piping systems specified in Skill Level 1, including such items as faucets, valves, pressure regulators, fire hydrants, and galley equipment; and diagnose trouble and make repairs or adjustments in any of the above.

Skill Level 3:

Not applicable.

Figure 1-3.—Individual rating skill definition.

410.1.01 TASK: Perform as Chainman.

Apply these ACTION STATEMENTS to the TASK ELEMENTS listed below:

- A. Describe the sequence of steps of this procedure and explain the reasons for each.
- B. List significant tools and materials used in this procedure.
- C. Describe principal materials used in this procedure.
- D. Discuss the parameters of this procedure.
- E. Describe assistance required while performing this procedure.
- F. Explain results if this procedure is not performed properly or is neglected.
- G. Perform the steps of this procedure when practical.

TASK ELEMENTS:

A B C D E F G

.01 Perform as head chainman:

- | | | | | | | |
|---|---|---|---|---|---|---|
| a. Select and set traverse station. | X | X | | X | X | X |
| b. Horizontal chaining using plumb bob. | X | X | X | X | X | |
| c. Break chaining using locke hand level | X | X | X | X | X | |
| d. Slope chaining using clinometer. | X | X | X | X | X | |
| e. Keep control point notes. | | X | | X | X | |
| f. Give and set foresight for angle turning | X | X | X | X | X | |

TASK ELEMENTS:

A B C D E F G

.02 Perform as rear chainman:

- | | | | | | | |
|----------------------------------|---|---|---|---|---|--|
| a. Give backsight for alignment. | X | X | X | X | X | |
| b. Hold tape or chain. | X | X | | X | X | |
| c. Drive and mark stakes. | X | X | | X | X | |
| d. Clear line of sight. | X | X | | X | X | |

.03 Transport, clean, and store:

- | | | | | | | |
|-------------------|---|---|--|---|---|--|
| a. Chains. | X | X | | X | X | |
| b. Range poles. | X | X | | X | X | |
| c. Plumb bobs. | X | X | | X | X | |
| d. Cutting tools. | X | X | | X | X | |

82.252

Figure 1-4.—Typical task analysis with task elements and related action statements.

USING THE STANDARDS AND GUIDES FOR INDIVIDUAL RATING SKILLS

When assigned as an interviewer, you must obtain, read, understand, and use the PRCP *Standards and Guides*. The format is standard. After the skill title, you will find the contents, the skill definitions, and the tasks, which are broken down into task elements. (See figs. 1-2 through 1-4.)

Skill Title and Contents

The title identifies the skill; for example, figure 1-2 identifies the individual Utilitiesman skill of

710, "Plumbing." The number 710 is a numerical code for this skill. The contents can be used to ensure there are no missing pages. The skill definition is always listed first and directly beneath it is .1 Skill Level 1. The tasks are listed under each skill level. You must interview each candidate to see if he or she is qualified for that skill level.

Skill Definitions

Figure 1-3 illustrates an individual rating skill definition. The definition shown is for "Plumbing" and is a statement of tasks to be performed at each skill level.

There are one, two, or three skill levels, depending upon the complexity and number of tasks. Each level within a given skill is more difficult to attain than the previous one and requires a broader knowledge in both application and theory. For example, a person having Skill Level 1 in "Plumbing" performs comparatively easy tasks; whereas, at Skill Level 2 and 3 that person must demonstrate a skill and knowledge factor for a much more complex phase of this specific area of the trade.

The purpose of the skill definition in the *PRCP Standards and Guides* is to introduce the skill material to the interviewees. In fact, you begin your interview by reading the skill definition. If the interviewees say they can do the related work, you may continue with the interview for the skill level; however, if they say they CANNOT do the work, it is obvious that you should go on to some other skill.

Task and Task Elements

A TASK is a specific portion of the overall skill level. (See fig. 1-4.) Many tasks cover relatively broad areas. Others may be quite specific and brief. Each task is further broken down into several smaller jobs called task elements.

A TASK ELEMENT is a basic part of each task. When interviewing, you use the task elements and their related ACTION STATEMENTS to determine the interviewee's qualifications. Action statements tell you the type of information you should get from the person being interviewed. Each action statement is identified in the guides by a capital letter (A, B, C, and so forth). They are listed near the top, and the number used varies from task to task. The first action statement in figure 1-4 is, "Describe the sequence of steps of this procedure and explain the reasons for each." A matrix is used to show how the statements relate to the task elements.

To gain familiarity with the matrix, refer to task element .01, "Perform as head chainman." Under the task element subparagraph a, you find "Select and set traverse station." If you follow this line and look to the right of this statement at the matrix, you see Xs under certain letters, indicating which action statements apply to this task element.

INTERVIEWING STEPS

When interviewing, the first thing you should do is to attempt to put the interviewee at ease.

A good way of doing this is to explain the purpose of the interview. For example, explain to the interviewee that the interview will

1. let him know what he is actually expected to know and to do,
2. determine what he can actually do so he can be assigned to the right job, and
3. determine his deficiencies so that he can be programmed to receive proper training.

Next, explain to the interviewee that he should discuss his knowledge of the skill honestly and that he should not be embarrassed if he doesn't know every item covered in the guides.

Tell the interviewee what skill and skill level he is being interviewed for. Read the skill definition to see if the person is knowledgeable of the subject.

Task Interviewing

Begin interviewing by reading the task. This directs the interviewee's concentration to the right area. Then rephrase the task in your own words. For example, you could rephrase it as follows: "The first thing we will discuss in surveying is the performance of the chainman."

Now read the first TASK ELEMENT ("Perform as head chainman") (fig. 1-4). When you apply this task element through ACTION STATEMENT A ("Describe the sequence of steps of this procedure and explain the reasons for each"), it sounds similar to the following: "Describe the sequence of steps a head chainman should take in selecting and setting traverse stations, and explain the reason for each step."

The above sentence is not a question. It is a statement that directs the interviewee to tell you what he or she knows about performing the steps of the prestart check and the reasons for performing them. There are no questions in the *PRCP Standards and Guides*; therefore, no answers are provided. The guides point out the areas to be discussed (in terms of TASK ELEMENTS and ACTION STATEMENTS); and the interviewee's replies are evaluated by the interviewer on the basis of his own personal experience, knowledge, and judgment.

It should be obvious now why all rating skill interviewers MUST be experienced in the skill for which they interview. The only way you can determine that the interviewee knows the task element is to thoroughly know it yourself. If you are unfamiliar with, or "rusty" in, any tasks in

the guides, you must study these areas thoroughly before attempting to interview anyone. Also, if you do not understand how a particular action statement is used with a task element, you must resolve this before interviewing. One way of doing this is to discuss the problem with others who are familiar with the skill.

Discuss the task element ONLY with the action statements indicated in the columns to their right by an X in the matrix. For example, in figure 1-4, only action statements A, B, D, F, and G are used with task element .02a. In task element .03a of the same figure, only action statements A, C, F, and G are applied. As an expert in the skill, you probably have the desire to ask questions about tasks not covered by the guides. You must avoid doing this, as you would have no applicable standard against which to gauge interviewees' replies. If you feel strongly that the guides can be improved, discuss your recommendation with the PRCP coordinator.

Scoring Interviews

If interviewees have a Navy Enlisted Classification (NEC) in the skill for which they are being interviewed, they are automatically assigned to that skill level without being interviewed for any of the lower skill levels. When interviewing, you should use a positive approach. The interviewees either do or do not know the skill. The decision is left up to the interviewer. ALL TASKS must be accomplished for each skill level. The results of the interview are then introduced into the PRCP system. The procedures used for doing this are contained in NAVFAC P-458, volume III, *Systems Documentation*.

TRAINING

Each training program is formulated to provide personnel with the skills needed to accomplish current missions and mobilization missions. The program is developed according to the pattern, priorities, and tempo established by the commanding officer. It covers many phases from orientation courses to special technical courses. The success of a training program depends upon operational commitments, policies, and directives from higher authorities; experience and previous training of the personnel assigned; and training facilities available. Although much of the construction training is provided by class A and C-1 advanced schools, as well as

special construction battalion training (SCBT) courses, additional skill and experience must be acquired.

TRAINING ORGANIZATION

Navy regulations state that the NMCB executive officer supervises and coordinates the work, exercises, training, and education of personnel in the command. The executive officer supervises the training of officers, coordinates the planning and execution of the training program and, when necessary, acts to correct deficiencies in the program. The executive officer does this in the capacity as chief staff officer (CSO). The executive officer's principal assistant is the plans and training officer (S-2).

Company commanders are directly responsible for the training of their company personnel and for fulfilling training goals established by the commanding officer. The company commanders help to formulate training programs, supervise training of subordinate officers, and direct technical military and general training of their companies. The battalion service department heads are responsible for individual training in their departments. They conduct training for advancement and administer the OPNAV-sponsored general training. Platoon leaders observe closely the training progress of personnel in their platoons. They directly supervise on-the-job construction and military training. All petty officers assume the responsibility for training their members and must be able to conduct effective training courses using lectures, discussions, project work, and so on.

The plans and training officer (S-2) is assisted by a permanently assigned staff of three or four petty officers and by additional personnel on a part-time basis as necessitated by the formal training work load. This group is headed by a chief petty officer (S-2C), and its members function as the unit's central training coordinators. Responsible for the entire training program, this group is concerned with the formulation and administration of the formal military training program and the technical training program which includes formal schools, Special Construction Battalion Training (SCBT), advanced base construction, and disaster recovery. The individual assignments to classes are formulated and administered within each company and must correspond to the guidelines established by the plans and training officer.

In the Amphibious Construction Battalion (PhibCB), the training officer may serve as assistant to the operations officer. The training officer arranges and schedules all formal training of officers and enlisted personnel, performing essentially the same duties as the plans and training officer in the Naval Mobile Construction Battalion (NMCB). However, the training program planned by the training officer of a PhibCB is tailored to meet the specialized mission of the PhibCB. It provides the knowledge that operational teams and crews apply in carrying out all phases of their primary mission. Included are seamanship, installation and operation of causeway piers, fuel systems, and beach salvage techniques.

TRAINING GUIDELINES

In general, training should be consistent with the following guidelines:

- It must be closely integrated and coordinated with daily operations of the battalion. The plan and organization for training that is adopted must not interfere with essential construction functions.
- Notwithstanding the guideline just listed, the construction schedule should not be so inflexible that it overlooks opportunities for training that might even expedite the construction schedule.

- Maximum advantage should be taken of the opportunity to derive training benefits from routine operations.

Figure 1-5 shows a typical battalion training organizational chart.

TRAINING NEEDS

Training for advancement is a continuous concern of all personnel within a battalion, whether at the company or platoon level.

In home port, training programs become the primary mission. The NMCB is expected to spend about 75 percent of the available man-days in formalized technical, military, and general training. In addition, the planning and estimating group may be considered to be involved with on-the-job training. Approximately 2 months before an NMCB returns to home port, it sends a training conference team to the home port regiment to prepare the training schedule for the battalion's home port stay. This team schedules the training required for the battalion to meet its readiness and construction tasking for its next deployment. They also coordinate home port support for berthing, supplies, and recreation. All personnel are trained in the areas of technical, military, and general topics. However, the program may be tailored to meet the specialized mission of the battalion's next deployment. If one of the projects scheduled is the construction of an airstrip, there will undoubtedly be a great deal

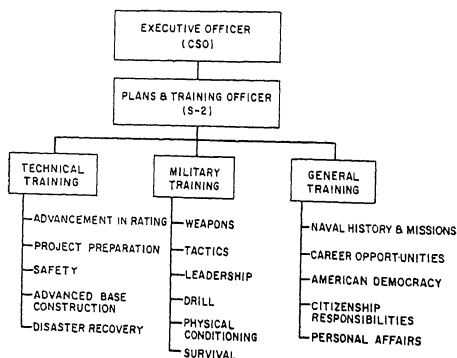


Figure 1-5.—Training organizational chart.

of site preparation going on. You will need to see how many qualified Construction Mechanics are available; you might need to train more personnel to maintain and repair specific equipment. Whenever an uncommon work item of sufficient magnitude is encountered during a forthcoming deployment, it should allow the majority of your personnel to gain experience and training in the operation.

Take inventory of the skills the members in your crew possess, whether through actual job experience or through some type of training program. After you have made this study, you can easily see whether the required skills for a particular job match the available skills. When they do not match, you have a good indication that training is needed to bring the crew up to the desired level of proficiency. In some cases, you will need to conduct refresher training; in other cases, you will have to provide instruction on new techniques.

As a supervisor, you may also check your personnel's service records, conduct a PRCP interview with each person, and select those best suited for training given at a Navy C-1 advanced school or at a special construction battalion training course.

ON-THE-JOB TRAINING

There are many forms of on-the-job training (OJT). It may be in the form of an especially tailored, well-organized program, such as one designed to help Utilitiesmen acquire advanced skills in air conditioning and refrigeration. Then again, OJT may be in the form of simple instruction, like explaining and showing a person how to tie a certain type of knot. In other words, when one person helps others to learn to do a job and makes sure they learn the right way, it is a form of OJT.

You may not have realized it, but in the Seabees, OJT goes on around us all the time. For instance, two strikers were assigned a job of copper pipe installation. Although they had performed many comparable jobs, they had not done that particular one. Their supervisor assigned an experienced crew member to guide them. This person explained the exact procedure for laying out the pipe; how it was marked, cut, and joined; and why that particular joint was necessary. The strikers understood and easily proceeded with the job.

There are as many examples of OJT as there are contacts between personnel in the Seabees. Its

importance becomes readily apparent in an organization, such as the Seabees, where changes in equipment, personnel, and improvements call continuously for new and better methods of doing construction work.

In the Seabees, as well as in private industry, the term *on-the-job training* has come to mean helping an individual acquire the necessary knowledge, skill, and habits to perform a specific job. This definition implies that the job training applies not only to the Constructionman or to the new personnel in an organization but also to any other person who is assigned a new job. It indicates that job training is a continual function in the Seabees. No person should be regarded as completely trained. One's performance can always be improved by keeping interest high and by passing on directions, suggestions, and information that will increase proficiency of the trainee.

Bear in mind, however, that OJT is an active process and requires supervisors who are aware of the needs of the trainees and who can motivate them to learn. Use methods that add meaningful experiences to the trainees' storehouse of knowledge.

A supervisor who does a good job of training personnel stands to benefit in many ways. For one thing, well-trained crew members brag about their supervisor, especially to their buddies in other crews. A remark they might make proudly is, "I sure do enjoy working for Petty Officer Smith because I learn so much." As you can see, this multiplies your effectiveness with the crew. If you have a skill, knowledge, or attitude of value to the Navy and impart that skill, knowledge, or attitude to 10 others—you have multiplied your effectiveness considerably.

Setting Up a Program

In setting up an OJT program, one of the first things you should do is to make an administrative analysis to determine the type of training required.

One of the training requirements may be for advancement in rate for your personnel. There is nothing that will make you feel prouder than to see Constructionmen that you have trained make third class petty officer. Do you know what they are thinking? Their thoughts are not, as commonly believed, "Oh boy, no more mess cooking." Their real thoughts are probably that they cannot wait until they can sew on the next stripe. In preparing a program, keep in mind the broad knowledge you have pertaining to the

training objectives and determine in which ways you can best use your experience. You have to determine, of course, the subjects to be taught.

You will have to break the subjects down into lessons, consider the length of time to be devoted to each subject, and determine if you are going to teach these subjects in a classroom, field, or shop. You may have to establish lesson sequence, determine lesson objectives, analyze reference materials, prepare lesson plans, and so on. Remember that in any type of training program, the objective is to help the trainee learn the most information in the shortest time possible.

Implementing a Program

You should consider various courses of action in implementing an OJT program. To the supervisor or trainer, some of the most important are as follows:

- Survey unit assignments and ensure each assignment is in the best possible accord with an individual's classification and specific skills background.

- Determine the exact need for training. To determine this need, establish two things: (A) the specific job requirements and (B) the individual skills of the trainee. When A and B are known, the OJT required can be stated in a simple formula.

A - B = OJT required

- Determine the method or methods of training that are most effective. The number of people, time available, facilities required, nature of training, and individual capabilities are factors that will affect your decision.

- Select the individuals who will actually conduct the training. You should remember that the end product will be no better than those who conduct the training program.

- Procure all available materials that may help supplement the program.

- Monitor the program continually to ensure it does not lag, that training records are kept current, and that newly developed skills are properly applied.

This is truly a large order. But now, more than ever, our Navy depends upon quality training. It is an important job, and it is one that never ends.

Training Methods

In OJT, you must be prepared to use a combination of training methods, depending upon the nature of the subject, time available, and the capabilities of the trainee. The following methods of training are basic to any well-planned unit training program.

No other method of training is as effective, as intelligent, or as interesting as coach-pupil instruction. In addition to being a quick way of fitting a new worker into the operation of a unit, it serves as one of the best methods of training. Without specific directions and guidance in learning to perform the necessary duties, a worker is likely to waste time and material and form bad work habits.

Many organizations in industry have apprenticeship programs designed to train workers in a trade or skill. Their training consists of coach-pupil instruction with skilled worker supervision and periodic group instruction when it is advantageous.

Self-study should be encouraged. Skilled and semiskilled jobs require a considerable amount of job knowledge and judgment ability. Even in simple jobs, there is much basic information a worker must acquire. The more complicated technical jobs involve both basic and highly specialized technical knowledge and related skills that must be taught.

Group instruction is a practical addition to direct supervision and self-study. It is a time-saver when several workers are to be instructed in the same job-related knowledge or procedures. The supervisor or trainer can check training progress and clarify matters that are difficult for the trainees to understand. Group instruction, if intelligently used, can speed up production. For example, suppose you have six trainees learning the same job. Four of the trainees are having trouble with a certain job element, while the other two have learned it. The four people having trouble can be brought over to the other two, and in a short time the difficulty will most likely be solved. In OJT, this is called group instruction. As you can see, group instruction is not the same as classroom or academic instruction.

Another type of OJT is piecemeal instruction. For instance, a crew member asks you for information and you supply it. That is piecemeal

instruction. A supervisor's orders are, in a sense, a piecemeal method of instruction because they let others know what, when, where, and perhaps, how and why. Other examples of piecemeal instruction are explaining regulations, procedures, and orders; holding special meetings; indoctrinating a new person; and conducting organized or unorganized meetings.

Training Development

In any type of effective training where one individual is working directly under the supervision of another, the trainers and trainees must understand the objectives of the training. Factors deserving careful consideration include determining the training needs of the trainees, defining the purpose of training, and explaining or discussing different points concerning training with the trainees.

In determining training needs, it is often a good idea to interview the trainees. A summary of previously acquired skills and knowledge relative to the job can be learned by proper questioning. Compare jobs the trainees know how to do with those they will be doing. Determine training needs (required knowledge and skills minus the knowledge and skills the trainees already possess). Training needs should be determined for each job pertaining to the trainee's position assignment. Analyze the job to be done and have all necessary equipment and materials available before each job training situation.

In defining the purpose of training, you should clearly explain the purpose of the job, duty, or task to be performed by the trainees. You should also point out to the trainees their place on the team and explain to them how they help in getting the unit's mission done. Stress the advantages of doing the job well, and how the training benefits them, their organization, and the Seabees.

The trainers should also explain facts about the job to be done, principles that are proven and workable, and directions on ways to do the job safely, easily, and economically. The trainers should explain, too, the techniques that will improve the skill of the trainees. The importance of each operation in a job should be stressed. The technical terms associated with the job should also be explained.

The trainers and trainees should discuss the problems that arise in doing a job, and try to clear up any questions the trainees may have concerning the job. Trainers should point out to the trainees

the similarity of different jobs. The relationship of procedures in a particular job, to things with which the trainees are acquainted, should also be discussed. This allows the trainees to learn through association with past experiences. It also is important for the trainers to discuss the progress of the trainees.

The most valuable end product of a peacetime military operation is trained personnel. Regardless of your unit's mission, you must have trained personnel to carry it out. It is the responsibility of every petty officer in the Navy to train the personnel under their immediate supervision. This responsibility should never be taken lightly.

SYSTEMATIC TRAINING

Effective training requires a great deal of planning and directed effort, organizing of materials into a logical sequence to prevent a haphazard approach to the job of training, and having an accurate method for measuring results. If any learning takes place, there must be some results. If you push as hard as you can on an object and there is no result—if you fail to move it—no work has been done regardless of the energy you expended. **If no learning takes place, you have not trained.** Three steps that may help you in planning and carrying out your training programs are as follows:

1. Ensure learning by using the correct training methods.
2. Measure achievement at regular intervals to assure that learning is taking place.
3. Record results so interested parties can check progress; records in the open can create competition that often is a great motivating factor.

Evaluation

It is nice to know that you are doing something worthwhile and that your efforts are appreciated. You and the trainee will want an evaluation of the work each does. Generally, the most valid trainer evaluation can be obtained by testing the trainees to see how much they have achieved under your guidance. If they have learned to perform in a highly satisfactory manner, this is an indication that you have done a good job of training. The effectiveness of the training is determined by how much training has taken place and the value of that training. The personnel must be trained correctly. Improper training, in many cases, is worse than no training at all.

Performance Testing

Performance testing helps you do a better job of conducting an OJT program. You can use performance tests to find how well your trainees are performing their jobs. However, it is difficult to find a test that does its job well.

Performance tests should enable you to rate the work of subordinates accurately enough to carry out the following objectives:

- To help determine whether trainees can actually perform the tasks they are being trained to do.
- To aid you in rating the improvement of persons undergoing OJT.
- To help you locate the strengths and weaknesses in OJT programs.
- To help you determine the qualifications of personnel entering OJT programs.
- To assist you in assigning new people to particular jobs.

Since it is a practical check on a work project, a performance test must be a sample work situation in which the trainee performs some active piece of work that can be examined. The test is not designed to measure what a person knows about the job (a written or oral test may fill that need for you). Instead, it is intended to help you rate that person's ability to actually do the job. Do the best you can in organizing and administering the performance test. There will always be room for improvement in most of the testing that you do.

DAILY WORK ASSIGNMENTS

The assignment of work is an important matter. On a rush job, you may have to assign the best qualified person available to ensure meeting the deadline. When time and work load permit, rotate work assignments, so each person has an opportunity to acquire skills and experience in the different phases of their rating. When assignments are rotated, the work becomes more interesting for the crew. Another good reason for rotating work assignments is to prevent a particular person from doing all the work of a certain type. This could be a severe disadvantage

if that person were to be transferred or hospitalized or go on leave for a lengthy period of time.

Give special consideration to strikers in work assignments. They should be assigned to jobs of increasing levels of difficulty. Strikers may be useful assistants on a complicated job, but they may not fully understand the different phases of the job unless they have worked their way up from basic tasks.

In assigning work, be sure to give the worker as much information as necessary to do the job properly. An experienced worker may need only a drawing and a general statement concerning the finished product. A less experienced worker is likely to require more instruction concerning the layout of the job and the procedures to be followed.

Often, you may want to put more workers on the job than it normally takes in order to get the job completed sooner. Remember, there is a limit to the number of workers that can be put on a job at any given time. But, do not overlook the advantage of assigning more crews or crew members to a project when their services can be effectively used or when the opportunity to learn a unique phase of the rating presents itself.

REPORTS

As you advance in rating, your job will require an increasing number of reports. Keeping all your reports up to date will enable you to check closely on each job, each crew member, and each piece of equipment under your supervision. Reports provide a means of checking job progress against the planned job progress. Your activity will have standard forms for keeping some of the required reports and for making certain supply transactions; for example, Equipment Requests (fig. 1-6), Utilities Excavation Permits (fig. 1-7), Construction Quality Control Reports (fig. 1-8), MLO Forms for Mineral Products for Projects in NMCB's (fig. 1-9), Enlisted Performance Evaluation Reports, Work Requests, and NMCB Job Orders. More information on reports for equipment and other forms can be found in the *Management of Transportation Equipment*, NAVFAC P-300; *Naval Construction Force Manual*, NAVFAC P-315; and *Inspection of Shore Facilities*, NAVFAC MO-322. In addition,

NMCB ____ EQUIPMENT REQUEST

PART A: To be completed by requester:

Date of request:
(3 copies required)

Project/Destination:

Requesting Company and Point of Contact:

Date and Time Equipment Required:

Type of Equipment Required:

Intended Use:

Operator Required: ____ YES. ____ NO.

Requester's Signature and phone number:

Project Supervisor's Signature:

Company Commander/Company Chief's Signature:

PART B: To be completed by Alfa Company

Received By and Date:

Approved _____. Disapproved for the following reason:

Signature (A3 approval required for all construction equipment):

USN NO: PM DATE:

Equipment Type:

Copy to:
REQUESTER
DISPATCH

Figure 1-6.—Equipment Request.

forms used for reports often are designed locally and differ somewhat from one activity to another. At most activities, you will find it helps to maintain logs, notebooks, and charts of your own design to meet specific needs.

ENLISTED PERFORMANCE EVALUATION REPORTS

The Navy Enlisted Performance Evaluation Report is a periodic recording of an individual's

qualifications, performance level in comparison to contemporaries, conduct, and prospects for increased responsibilities. It is the most significant personnel management tool in the enlisted service record. It is primarily designed for use by the Commander, Naval Military Personnel Command (COMNAV MILPERSCOM), in making advancement and assignment decisions. It is also used in determining a person's eligibility for the Good Conduct Medal, reenlistment, and character of service at time of

EXCAVATION REQUEST (Submit in Triplicate) _____ Date: _____

From: _____
 (Organization) (Point of Contact) (Telephone No.)

To: Public Works Officer, _____

Request for Clearance to Excavate for the Purpose of:
 (Description of Excavation Proposed) _____

Method of Excavation: _____

Planned Start Date: _____ Estimated Completion Date: _____
 (including backfill, compaction,
 ground cover, paving repair, etc.)

Plot plan/sketch is mandatory and attached
 showing location of planned
 excavation. (Allow 4 work-
 days for processing)

 Signature (Requesting Official)

INTERNAL PUBLIC WORKS DEPT ROUTING

Public Works Utilities Div Endorsement:

PWU LINE CREW: _____ APPROVAL/DISAPPROVAL DATE: _____

 Signature

PWU WATER CREW: _____ APPROVAL/DISAPPROVAL DATE: _____

 Signature

COMMENTS: _____

PWE: _____ APPROVAL/DISAPPROVAL DATE: _____

 Signature

COMMENTS: _____

PUBLIC WORKS DEPT ENDORSEMENT

From: Public Works Officer, _____ Date: _____
 To: _____
 Approved _____ Originator _____
 Disapproved _____

 Approving Official

Figure 1-7.—Utilities Excavation Permit.

INSPECTOR'S REPORT (QUALITY CONTROL DEPT.)

NMCB

2313/1 (REV. 2-83)

ROUTE TO	INITIAL	DATE	REMARKS
S3			
S3C			
S3QC			
S3S			
Prime			
Sub			

DATE	TIME	PROJECT NO.	REPORT NO.
PRIME CO.	PROJECT TITLE		
SUB CO.	WEATHER		
SUPERVISOR		INSPECTOR	

ACTIVITY	RATE	DESCRIPTION OF WORK PERFORMED

ACTIVITIES STARTED	ACTIVITIES COMPLETED

CONSTRUCTION INSPECTION PLAN ITEMS CHECKED	RESULTS

DELAYS	SAFETY HAZARDS PRESENT

REMARKS

MATERIAL RECEIVED

CERTIFY ALL WORK PERFORMED THIS DATE IS IN ACCORDANCE WITH PLANS AND SPECIFICATIONS

PROJECT SUPERVISOR	QC INSPECTOR	REVIEWED (S30)	APPROVED SIGNATURE

DATE

1. ROICC
2. QC FILE VIA S-3
3. LEAD COMPANY

Figure 1-8.—Construction Quality Control Report.

 Date

From: _____ Project Supervisor
 To: _____
 Via: MLO, NMCB _____
 S3, NMCB _____

Subj: PROJECT NUMBER/TITLE: _____/
 BM CODE/LI: _____/

Encl: (1) Completed 1250 for requested material

1. It is requested that the following mineral product be provided as follows:
 (Only one product per request)

a. 2" MINUS _____ CY	g. CONCRETE _____ CY
b. 3/4" CLEAR _____ MT	PSI: _____ AGGREGATE: _____ SLUMP: _____
c. 3/8" CLEAR _____ MT	h. ASPHALT _____ MT
d. BEDDING SAND _____ CY	GRADATION: _____ MIN TEMP: _____
e. WASH SAND _____ CY	i. OTHER _____
f. MORTAR MIX _____ CY	j. SITE LOCATION (Bldg #, Street, etc.) _____

k. DATE/TIME REQUIRED: _____
 _____/_____/_____

l. CONCRETE AND ASPHALT: (1) CY/MT PER TRUCK _____
 (2) INTERVAL BTWN TRUCKS _____
 (3) NO. OF TRUCKS RQD _____

m. SPECIAL INSTRUCTIONS/COMMENTS/LOCAL MATL INST: _____

2. Review/comments (S3QC): _____

3. Review/comments/order data (MLO): _____

4. Contact person(s)/phone #: _____/
 _____/_____

5. Submitted by: _____ (Project Chief - Keep copy)

6. Approved:

S3QC: _____	_____ DATE
MLO: _____	_____ DATE
A6: _____	_____ DATE

NMCB _____ MLO Form 4000/01 (6-85)

Figure 1-9.—MLO Form for Mineral Products for Projects in NMCB's.

discharge. Various selection boards use performance evaluation reports to select members for advancement, continuation of active duty, retention, appointment to commissioned status, assignment to special duties, and special educational programs. The performance appraisal process cannot be overemphasized and it demands command attention.

As a first class petty officer, it is your job to see that the rough draft of the evaluation report

is filled out clearly. You can get a copy of NAVMILPERSCOMINST 1616.1A or *Military Requirements for Petty Officer First Class*, NAVEDTRA 10046-A, chapter 3, to show you what information goes in each block. See that you have the Enlisted Performance Evaluation Report—Individual Input, NAVPERS 1616/21, filled out by each person on whom you are making an evaluation report. (See fig. 1-10.) All of the blocks must be filled in before you forward it through the chain of command. (See

ENLISTED PERFORMANCE EVALUATION REPORT - INDIVIDUAL INPUT NAVPERS 1616/21 (8-76) S/N 0106-LP-016 1705		DATE PREPARED	DEPARTMENT
NAME (last, first, middle)		RATE	PRESENT SHIP OR STATION

THE SUBMISSION OF THIS FORM IS A MEANS OF ENSURING THAT YOUR PERSONAL ACCOMPLISHMENTS, ACHIEVEMENTS AND CREDITABLE ACTIVITY DURING THE CURRENT REPORTING PERIOD ARE BROUGHT TO THE ATTENTION OF YOUR REPORTING SENIOR THROUGH THE CHAIN OF COMMAND.

1. IN RATE AND NORMAL DUTY QUALIFICATIONS ACHIEVED
2. SPECIAL QUALIFICATIONS ACHIEVED
3. IN RATE PROFESSIONAL DEVELOPMENT
4. OTHER EDUCATIONAL AND TRAINING ACCOMPLISHMENTS
5. VOLUNTARY NAVY RELATED CIVIC AND COMMUNITY SUPPORT ACTIVITY
6. OTHER CIVIC AND COMMUNITY SUPPORT ACTIVITY
7. COMMENDATORY CORRESPONDENCE RECEIVED DURING THIS REPORT PERIOD
8. OTHER ACHIEVEMENTS, ACCOMPLISHMENTS, AND SIGNIFICANT EVENTS/ACTIONS

NOTE: THE USE OF THE INFORMATION PROVIDED BY THE RATEE IS DISCRETIONARY ON THE PART OF THE REPORTING SENIOR. UPON COMPLETION OF THE EVALUATION REPORT, THIS FORM SHALL BE RETURNED TO THE RATEE.

Figure 1-10.—Enlisted Performance Evaluation Report—Individual Input.

1 NAME (Last, First, Middle or Middle Initial)		2 RATE/RATING		3 SSN								
4 <input type="checkbox"/> USN <input type="checkbox"/> USNR		5 <input type="checkbox"/> ACTIVE <input type="checkbox"/> INACTIVE <input type="checkbox"/> TEMAC		6 <input type="checkbox"/> ACCUTRA								
10 MEMBER'S SHIP OR STATION		11 MEMBER'S UIC		12 DATE REPORTED								
13 <input type="checkbox"/> Periodic <input type="checkbox"/> Transfer <input type="checkbox"/> Other		16 From		17 To								
18 TYPE OF REPORT <input type="checkbox"/> Con <input type="checkbox"/> Currnt <input type="checkbox"/> Other		19 HEIGHT & WEIGHT/PHYS. QUAL.		20 RESERVE PART								
21 REGULAR <input type="checkbox"/> Regular <input type="checkbox"/> Current <input type="checkbox"/> Other		22 EFF DATE OF RATE										
23 REPORTING SENIOR'S NAME (Last and Initial)		24 RANK		25 TITLE								
26 SSN												
EVALUATION SECTION <i>(Requires Comment)</i>		NOT OBS	4.0	3.8	3.6	3.4	3.2	3.0	2.8*	2.6*	2.4*	1.8*
PROFES- SIONAL FACTORS	27 MILITARY KNOWLEDGE/ PERFORMANCE											
	28 RATING KNOWLEDGE/ PERFORMANCE											
	29 INITIATIVE											
	30 RE: ABILITY											
	31 MILITARY BEARING											
PERSONAL TRAITS	32 PERSONAL BEHAVIOR											
	33 HUMAN RELATIONS INCL EQUAL OPPORTUNITY											
	34 SPEAKING ABILITY											
	35 WRITING ABILITY											
	36 DIRECTING											
LEADERSHIP	37 COUNSELING											
	38 MANAGEMENT <i>(If 3, 4, & 5 Only)</i>											
39 OVERALL EVALUATION												
40 SUMMARY <i>(Required for E-4 & Above)</i>												
41 ADVANCEMENT RECOMMENDATION 41 <input type="checkbox"/> Recommended 42 <input type="checkbox"/> Progress 43 <input type="checkbox"/> Not Recommended		44 SIGNATURE OF REPORTING SENIOR										
44 SIGNATURE OF MEMBER <i>I acknowledge that I have seen this evaluation report and understand my rights under Article 1110, U.S. Navy Regulations (1973) to submit a statement. Statement Desired/Not Desired (cross out as appropriate)</i>		45 ADDRESS OF REPORTING SENIOR										
47 TYPED NAME AND SIGNATURE OF REGULAR REPORTING SENIOR ON CONCURRENT REPORT		46 DATE FORWARDED										
		46 DATE PWD (If 47 Used)										

NAVPER 1616/24 (6-82) SN 0106-LF-016-1720
Report NMPC 1616-1

GPO: 1963-687-021/1326

Figure 1-11.—Enlisted Performance Evaluation Report (front).

OCR TYPING FONT NOT REQUIRED FOR COMPLETION OF THIS SIDE			
50 MEMBER'S LAST NAME, INITIALS	51 SSN	PERIOD OF REPORT 52 From 53 To	
54 DUTIES AND RESPONSIBILITIES			
55 SPECIAL ACHIEVEMENTS			
56 EVALUATION COMMENTS			

Figure 1-12.—Enlisted Performance Evaluation Report (back).

24.73

figs. 1-11 and 1-12.) Preparation of rough evaluations reports is your single most important administrative task. It is important for you to be thorough, timely, and fair. Give the continuing evaluation of your personnel top priority.

As a first class petty officer, you will write evaluations in the rough on people in paygrades E-1 through E-5. The evaluations for people in paygrades E-1 through E-3 do not include narrative remarks. The evaluations for people in paygrades E-4 (PO3) do not include narrative remarks but should contain a listing of significant qualifications achieved during the reporting period. Evaluations for people in paygrades E-5 (PO2) include narrative remarks and all of the blocks must be filled in. Some comments that may help you are as follows:

Paragraph 1. First sentence. Use one to three adjectives that best describe the person plus a statement concerning overall performance. (The more adjectives, the better the person.) State the person's job within the sentence and how it relates to the command's mission. Be careful not to use redundant adjectives.

Example: Petty Officer Seabee is self-motivated, resourceful, and can be relied upon to complete difficult assignments without direction or guidance. Is aggressive and initiates workable ideas for ways of doing things more accurately, more quickly, and more thoroughly with the same means and resources as his contemporaries.

Second sentence. Use words related to leadership ability and describe his effectiveness in integrating people with the mission. Discuss difficulty of billet, number of people being supervised, and where appropriate, the dollar value of the equipment for which he is responsible.

Example: Sets and maintains a high standard of performance for himself and subordinates. Maintains a high state of operational and material readiness. In the supervision of five assigned personnel, he is extremely firm and fair. He is responsible for the operation and working condition of equipment valued at \$2 million dollars.

Third sentence and remainder of paragraph 1: Words related to technical competence on the job.

Example: He continually maintains a high state of operational and material readiness despite antiquated equipment and non-availability of spare parts and material support.

Paragraph 2. List of solid accomplishments taken from individual input. Do not overdo the superlatives. Talk about facts that are a matter of record. This part should be "hard hitting," in bullet format, capitalized, and underlined for emphasis.

Example: Contributed significantly to the department achieving zero report deficiencies in

FY 87's TYCOM Inspection. Received numerous superlative comments from the inspection team regarding condition of the equipment.

Paragraph 3. Attaboys, if any. Quote unclassified citations; paraphrase classified citations. State the source of the citation. If signed by an admiral, state his name. For unit attaboys, tie in personal performance as a key to unit success if in fact, the person was a significant contributor to the successful evolution.

Example: Received CO's letter of appreciation for superior preparation of facility for change of command.

Received letter of appreciation from OIC, NAS Annex, for volunteer work on their emergency generator during a station power outage.

Paragraph 4. Specific aspects of performance. Comment on any particularly outstanding or adverse mark assigned. Personal traits may be mentioned. Identify extracurricular activities that have been of benefit to the Navy. Comment on family involvement that has been an influential factor in the person's performance.

Example: Petty Officer Seabee is deeply involved in many community activities. He is a Boy Scout troop leader, a youth counselor at the local Boys Club, and a deacon on the First Baptist Church council. He is an excellent representative of the U.S. Navy.

Paragraph 5. Recommendations. Cover the following items, as appropriate:

- Next duty
- Augmentation/officer programs
- Potential for C school, or special education
- Retention and promotion

The strength of the above recommendations must match the overall strength of the evaluation. The report must be accurate, hard hitting, and to the point. Flowery language is of no value. When a person is good, say so and back it up with examples. Above all else, the evaluations must be

consistent with performance. It must track with monthly and/or feeder evaluations for enlisted personnel.

WORK REQUESTS AND JOB ORDERS

As a shop supervisor, your work involves work requests and job orders. A work request, as the name implies, asks that work be done. A job order is issued primarily for the purpose of specifying what work is to be done and when it is to be accomplished. A job order also provides for the accumulation of cost data. Since the job order procedure is not the same at all activities, you must learn the procedure for your particular activity and follow it carefully; this will help ensure that jobs are accomplished without undue delay.

Wherever work requests and job orders are concerned, it is important for a work control system to be established that designates who may request work, what type of work may be requested, and who will approve the request authorizing the job order. In the public works department, control and responsibility are normally designated within the work classification system. The public works department uses eight classifications of work as follows:

1. Emergency work
2. Service work
3. Minor work
4. Specific job orders
5. Standing job orders
6. Supplements to authorized work
7. Amendments to authorized work
8. Rework

EMERGENCY WORK requires immediate action and includes the following:

- Prevent loss or damage to government property.
- Restore essential services disrupted by a breakdown of utilities.

- Eliminate hazards to personnel and equipment.

Emergency or service work authorizations are limited to 2 man-days. When the work requires more than 2 man-days, emergency work initiated by an emergency work authorization must be superseded by a minor work authorization or by a specific job order, whichever is appropriate.

SERVICE WORK is relatively minor in scope, can be accomplished within 2 man-days, is not emergency work by nature, and does not exceed the predetermined dollar limitation. The work reception and control branch is authorized to approve \$75 to \$150, depending upon the size of the activity.

MINOR WORK is work in excess of that already authorized by an emergency or service work authorization and less than that authorized by a specific job order.

SPECIFIC JOB ORDERS authorize the accomplishment of a specific amount of work for which individual job costs are needed for financial and performance evaluation purposes.

STANDING JOB ORDERS include all work that is highly repetitive on which accumulated costs are needed for a specified period, usually a fiscal year. Some examples are trash and garbage disposal, power plant watch standing, public works engineering, leave cost, and shop overhead.

SUPPLEMENTS TO AUTHORIZED WORK are issued for any portion of the work under a basic job order that is to be initially charged to an accounting classification other than that shown on the basic job order. A supplementary job order may be issued under a specific or standing job order.

A specific, standing, or supplementary job order may use an **AMENDMENT TO AUTHORIZED WORK** for various reasons including the following:

- To reopen a closed job order
- To modify technical provisions

- To increase or decrease the scope of a job
- To increase or decrease the dollar estimate
- To change the accounting classification

REWORK is work that, in the judgment of the public works officer, is necessary to correct faulty work by public works department personnel.

Certain types of work require prior approval or authorization of the commanding officer, management bureau, or higher authority. However, issuing job authorizations to the public works shop is the responsibility of the public works officer or his delegated representative. Although job authorization is, in effect, signing of the authorizing document, this act presupposes knowledge and approval of every item contained in the work request. Job authorization, therefore, presumes an understanding of the principles and workings of controlled maintenance, as well as familiarity with the work to be approved.

The public works officer may approve and sign any or all work authorizations within limitations established by the cognizant management bureau of the commanding officer. In actual practice, the public works officer usually approves and signs only those documents authorizing work that exceeds the limitations for authorization established by him for the director of the maintenance control division. The assistant public works officer may approve and sign any or all of the work authorization documents when such authority has been specifically delegated by the public works officer.

The director of the maintenance control division may approve and sign any or all work authorization documents that do not exceed the monetary limitations imposed by the public works officer. The engineer of the shop may approve minor work, service work, and emergency work authorizations. The director of the maintenance or utilities division may approve minor work, service work, and emergency work authorizations. The work reception and control branch (maintenance control division) may approve and sign emergency work and service work authorizations within the limits established by the public works officer.

At times, it may be necessary for you to make up work requests or job orders. Requests for all work, except service and emergency, are prepared on a Work Request, NAVFAC 9-11014/20. (See fig. 1-13.) Job orders are prepared from these

requests on a Work Authorization/Estimate, NAVFAC 11014/22, and a continuation sheet, NAVFAC 11014/22A. (See fig. 1-14.) For emergency or service work, an Emergency or Service Work Authorization, NAVFAC 9-11014/TF-21,

WORK REQUEST (MAINTENANCE MANAGEMENT)		UPW Department use Instructions in NAVFAC MO-371	
Requester use Instructions on Reverse Side			
PART I—REQUEST (Filled out by Requester)			
1. FROM	Supply Officer	2. REQUEST NO.	12-711
3. TO	Public Works Officer	4. DATE OF REQUEST	26 June 19--
5. REQUEST FOR	<input type="checkbox"/> COST ESTIMATE <input checked="" type="checkbox"/> PERFORMANCE OF WORK	6. REQUEST WORK START	
8. FOR FURTHER INFORMATION CALL	LTJG L. Moore Bldg. C. Ext. 891	7. SKETCH/PLAN ATTACHED	<input type="checkbox"/> YES <input checked="" type="checkbox"/> NO
9. DESCRIPTION OF WORK AND JUSTIFICATION (Including location, type, and quantity, etc.)			
<p>Fabricate and erect extension to wood storage rack, southwest corner, Bldg. 107. Start from the south wall and extend through bays 3-4 approx: 30' long 2' deep 10' high</p> <p>Storage rack to be anchored to wall and have 5 shelves spaced approx. 2' apart. Shelves should be capable of storage of material weighing up to 5 lbs. per sq. ft. No paint required.</p> <p>Extra storage space needed for small shop store items.</p>			
10. FUNDING CHARGEABLE		11. REQUESTER USE ONLY	
37602 (SEA)		J. R. BROWN, LCDR, USN	
PART II—COST ESTIMATE			
(Filled out by Maintenance Control Division if estimate requested)			
12. TO	Supply Officer	13. ESTIMATE NO.	307
13. COST ESTIMATE		14. SKETCH/PLAN ATTACHED	
a. Labor	\$ 140.	<input type="checkbox"/> YES <input checked="" type="checkbox"/> NO	
b. Material	\$ 90.	<input type="checkbox"/> APPROVED. PROGRAMMING TO START IN _____	
c. Overhead and/or Burcharge	\$	<input checked="" type="checkbox"/> APPROVED. BASED ON PRESENT WORKLOAD, THIS JOB CAN BE PROGRAMMED TO START IN 30 days IF	
d. Equipment Rental/Usage	\$	AUTHORIZED BY 35th OF _____ AND FUNDS ARE MADE AVAILABLE.	
e. Contingency	\$ 25.	<input type="checkbox"/> DISAPPROVED (See Reverse Side)	
f. TOTAL	\$ 255.	15. SIGNATURE	16. DATE
		William B. King	3 July 19--
PART III—ACTION (Filled out by Requester)			
Public Works Officer			
17. AUTHORIZATION TO PROCEED IS ATTACHED (Check one if other than PW funds are involved)			
<input checked="" type="checkbox"/> NAVFAC MO-371 <input type="checkbox"/> OTHER			
18. SIGNATURE	J. R. BROWN, LCDR, USN	19. WORK REQUESTED	<input type="checkbox"/> HAS BEEN CANCELLED <input type="checkbox"/> HAS BEEN DEFERRED <input type="checkbox"/> WILL BE PERFORMED BY OTHERS
		20. DATE	8 July 19--
(See Part IV on Reverse Side)			

Figure 1-13.—Work Request, NAVFAC 9-11014/20.

117.294

WORK AUTHORIZATION/ESTIMATE (MAINTENANCE MANAGEMENT)				ESTIMATE NO.	
CONTINUATION SHEET				50-001-89	
WORK AUTHORIZED 7/15/89 BY 237				807456	
LINE NO.	DESCRIPTION	QTY	UNIT	QTY	UNIT
1	CAR				26*
	CONSTRUCT A PARTITION 30' LONG, 12' HIGH, 2"x4" STUDS, 16" O-C, 1/2"x4"x8" GYP. BOARD, BASEBOARD, SHOE AND CEILING COVE—ONE SIDE ONLY (LEAVE STUDS OPEN ON INSIDE OF NEW OFFICE SPACE FOR OTHER CRAFT WORK).				
2	PPE				5*
	INSTALL 1 1/2" WASTE LINE TO WATER COOLER, CONNECT TO EXISTING WASTE LINE IN CRANL SPACE. INSTALL 1 1/2" VENT AND CONNECT TO EXISTING VENT STACK IN ATTIC. INSTALL 1/2" COLD WATER SUPPLY LINE TO COOLER, CONNECT TO SUPPLY LINE IN CRANL SPACE. INSTALL VALVE AT COOLER END. USE COPPER TUBING.				
3	ELE				36*
	REMOVE (8) EXISTING INCANDESCENT LIGHT FIXTURES AND 140" WIRE AND CONDUIT. INSTALL NEW (8) CIRCUIT DISTRIBUTION PANEL, CONDUIT, OUTLET BOXES FOR FLUORESCENT LIGHTS AND RECEPTACLES, AND PULL WIRES.				
4	PPE				9*
	INSTALL 2" STEAM SUPPLY AND 3/4" CONDENSATE LINES TO RADIATORS AND CAP OFF ABOVE FLOOR. (CONNECT INTO EXISTING LINES IN CRANL SPACE) (STEEL PIPE). INSULATE 2" STEAM SUPPLY LINE AND FITTINGS (FIBER-GLASS INSULATION).				
5	CAR				16*
	INSTALL 1/2"x4"x8" GYP. BOARD, BASEBOARD, AND CEILING COVE ON NEW PARTITION INSIDE. INSIDE CHAIR RAIL ON ALL INTERIOR WALLS. IN-STALL PRESHUING DOOR AND JAMB (DO NOT INSTALL SHOE MOLD AT THIS TIME).				
6	ELE				20*
	INSTALL (18) FLUORESCENT LIGHT FIXTURES, (6) RECEPTACLES AND CONNECT WIRES.				

WORK AUTHORIZATION/ESTIMATE (MAINTENANCE MANAGEMENT)				ESTIMATE NO.	
CONTINUATION SHEET				50-001-89	
WORK AUTHORIZED 7/15/89 BY 237				807456	
LINE NO.	DESCRIPTION	QTY	UNIT	QTY	UNIT
1	CAR				26*
	CONSTRUCT A PARTITION 30' LONG, 12' HIGH, 2"x4" STUDS, 16" O-C, 1/2"x4"x8" GYP. BOARD, BASEBOARD, SHOE AND CEILING COVE—ONE SIDE ONLY (LEAVE STUDS OPEN ON INSIDE OF NEW OFFICE SPACE FOR OTHER CRAFT WORK).				
2	PPE				5*
	INSTALL 1 1/2" WASTE LINE TO WATER COOLER, CONNECT TO EXISTING WASTE LINE IN CRANL SPACE. INSTALL 1 1/2" VENT AND CONNECT TO EXISTING VENT STACK IN ATTIC. INSTALL 1/2" COLD WATER SUPPLY LINE TO COOLER, CONNECT TO SUPPLY LINE IN CRANL SPACE. INSTALL VALVE AT COOLER END. USE COPPER TUBING.				
3	ELE				36*
	REMOVE (8) EXISTING INCANDESCENT LIGHT FIXTURES AND 140" WIRE AND CONDUIT. INSTALL NEW (8) CIRCUIT DISTRIBUTION PANEL, CONDUIT, OUTLET BOXES FOR FLUORESCENT LIGHTS AND RECEPTACLES, AND PULL WIRES.				
4	PPE				9*
	INSTALL 2" STEAM SUPPLY AND 3/4" CONDENSATE LINES TO RADIATORS AND CAP OFF ABOVE FLOOR. (CONNECT INTO EXISTING LINES IN CRANL SPACE) (STEEL PIPE). INSULATE 2" STEAM SUPPLY LINE AND FITTINGS (FIBER-GLASS INSULATION).				
5	CAR				16*
	INSTALL 1/2"x4"x8" GYP. BOARD, BASEBOARD, AND CEILING COVE ON NEW PARTITION INSIDE. INSIDE CHAIR RAIL ON ALL INTERIOR WALLS. IN-STALL PRESHUING DOOR AND JAMB (DO NOT INSTALL SHOE MOLD AT THIS TIME).				
6	ELE				20*
	INSTALL (18) FLUORESCENT LIGHT FIXTURES, (6) RECEPTACLES AND CONNECT WIRES.				

Figure 1-14.—Work Authorization/Estimate.

[illegible]

117.295A
Figure 1-15.—Emergency or Service Work Authorization,
NAVFAC 9-11014/TF-21.

is used. This form is shown in figure 1-15. The work request becomes a job order when it is authorized.

In making up a work request or a job order, furnish a clear description of the work to be performed and include all pertinent drawings and details. An accurate description of the work required is necessary, so the proper number and type of skilled personnel can be assigned to the job.

You may be in an NMCB working with job orders concerning military construction (MILCON). A typical job order from an NCR to an NMCB is shown in figure 1-16. The job order form is explained below.

WORK ORDER NUMBER: An assigned accounting number used to control and

accumulate charges of material and labor against the project.

LINE ITEM: The MILCON line item number that identifies the particular project.

JOB TITLE: A short, general description of the work to be performed.

DoD CAT CODE: The DoD facility category code under which the work is being assigned.

QUANTITY: The scope of the facility being constructed in terms of DoD category units of measure.

ESTIMATED MAN-DAYS: An estimate of direct labor man-days required to do the work described.

ESTIMATED COST: Dollar cost estimate to complete the project.

CUSTOMER ACTIVITY: The activity or command for whom the work is to be performed.

REPRESENTATIVE: An official designated to provide liaison between the construction unit and the customer.

TELEPHONE: The telephone number of the representative.

DESIGNATED FOR ACCOMPLISHMENT:
Construction unit that is to perform the
task.

AUTHORIZED BY: Name and signature of
the authorizing official.

GENERAL DESCRIPTION AND REMARKS: A brief, general description of the work and other pertinent data, such as special specifications.

REFERENCE: Identification of references pertaining to the construction project.

ENCLOSURE: Identification of drawings, specifications, and so forth, that are being forwarded with the work order.

INSTALL TASK NO: Numerical identification of sub-tasks to be performed by the

BEGIN DATE: Estimated or actual calendar date the sub-task will commence.

FINISH DATE: Estimated or actual calendar date the sub-task will be completed.

SIGNATURE AND DATE: Signature of construction unit representative and date of signature.

When you, as a supervisor, receive a job order, examine it carefully. Make sure you have a clear picture of what is to be done, who is to do it, and when. Be sure you have all of the information necessary to do the job. If material listings and drawings are listed on enclosures, make sure they have been included and check them for accuracy. If you have been designated as prime contractor or lead shop, see that the subcontractors or other shops have received the job order, prints, and material list as required. Check availability of material. Material support may vary greatly. On some jobs, you may not receive the job order until after all the materials required for the job have been received. On other jobs, you may have to order the materials yourself through a material yard, shop store, or the Navy Supply System. If you have any questions, get them answered before starting the job.

Ensure all of the material is properly charged to the correct job order number and that the material is used on the job for which it is drawn. Also, ensure that the labor required is charged to the proper job order number. This will keep you from the embarrassing position of trying to explain

how a job was completed without someone working on it.

MAINTENANCE AND UTILITIES FORMS

In a public works department, most supervisory positions held by a first class petty officer are located in the maintenance division or in the utilities division. Here, you will see many types of forms and reports. Most of these forms and reports are standard within the system; however, some of them are standard only to the local activity. In either case, they are the tools you need to increase the productivity of the work force.

REFERENCES

Military Requirements for Petty Officer First Class, NAVEDTRA 10046-A, Naval Education and Training Program Management Support Activity, Pensacola, Fla., 1987.

Naval Construction Force Manual, NAVFAC P-315, Naval Facilities Engineering Command, Alexandria, Va., 1985.

Personnel Readiness Capability Program, NAVFAC P-458, Naval Facilities Engineering Command, Alexandria, Va., 1981.

The Navy Enlisted Performance Evaluation System, NAVMILPERSCOMINST 1616.1A, Department of the Navy, Washington, D.C., 1988.

CHAPTER 2

LEADERSHIP AND SUPERVISION

Learning Objective: Compare leadership and supervision; analyze the differences between the two, and assess the methods recommended for use.

As a first class petty officer, your duties include leadership and supervision. To help you in fulfilling these duties, this chapter has been included to increase your awareness of the leadership and supervision competencies and to build your skills in these areas. The knowledge and use of these competencies will help you perform your duties more effectively. Now, what are competencies? In general, competencies are the knowledge, behavior, thought patterns, and skills that can be shown to distinguish reliably between effective and ineffective leadership and supervision.

LEADERSHIP

In this chapter, several concepts of leadership and human behavior are presented. Some you may already know; some may be new to you. Since there is no single way of leading that is always best for every person or for every situation, you may want to experiment with these concepts to find those that work best for you.

As you develop new insight into human behavior, your leadership ability increases; therefore, your subordinates should do their work better. This is your reward. Leaders are evaluated, not so much by their technical expertise, but by their ability to increase the effectiveness of their people in getting the job done. The reward for the Navy is better people and more production. The Navy has the best equipped ships, aircraft, and weapons systems money can buy; but only well-trained, dedicated people can make these systems work.

You have a lot of experience with people in many different situations. As you study this material, use your experience. When you come to a principle of human behavior, actively think

about it and tie it in with your past experience. When help is needed to clarify your ideas, talk about it with someone whose opinion you respect. A better understanding of your responsibilities and actions in carrying out your Navy leadership roles—getting Navy tasks done through the effective use of personnel—will have far-reaching rewards for you and the Navy.

DEFINITION OF LEADERSHIP

As a senior petty officer, what does leadership mean to you? Your ideas about leadership may differ from other petty officers' ideas. One might say, "leadership is the ability to inspire your people"; another might say, "leadership is the ability to keep your people in line." To some people, it is just getting the job done. To others, it is not only getting the job done, but getting the job done well.

When leaders get the required work done with the whole-hearted support of their people, this shows good leadership. However, if what is done produces dissension, disorganization, or inefficiency, effective leadership is not being practiced.

To be effective, leaders must earn and maintain the confidence, respect, and cooperation of their people. It has been said that leaders are known by the way they develop their people. When an interest is shown in people and they are guided in a way that uses their talents, capabilities, and skills, they, in return, become interested in and more responsible for their work. This increases their knowledge and ability to do the job. Tangible results help to identify the effective leader. Leaders are known by the results of their actions.

Leadership, then, can be defined as the art of influencing and directing people to win their

confidence, respect, willing obedience, and cooperation to achieve a common objective.

For a clearer understanding of leadership, let us distinguish between the concept of leadership and the leader's role as a supervisor. The leader's role depends on a formal grant of authority, normally from one's superior. Leadership is based on respect from those being led. It is an earned authority. This grant may be the sole authority, or it may be in addition to the formal grant of authority that characterizes the role of an officer or petty officer. The basis of all leaders' earned authority is personality, expert knowledge, problem-solving ability, and so forth. Often this earned authority is a composite of these traits. But, whatever the reason, people are leaders only if they are willingly followed by others.

PRINCIPLES OF LEADERSHIP

Leadership is an art. It requires the ability to organize, delegate, and coordinate. These are traits which you, the supervisor, should apply daily on the job. You can learn to organize, delegate, and coordinate in the same way you learn any other skill. Developing this type of skill is a continuing process.

Military leadership is NOT inborn; it becomes a matter of understanding and of applying sound leadership principles and techniques, as given below.

1. Be technically and tactically proficient.
2. Know yourself, and seek self-improvement.
3. Know your personnel, and look out for their welfare.
4. Keep your personnel informed.
5. Set a good example.
6. Ensure the task is understood, supervised, and accomplished.
7. Train your personnel as a team.
8. Make sound and timely decisions.
9. Develop a sense of responsibility in your subordinates.
10. Employ your crew members according to their capabilities.
11. Seek responsibility, and take responsibility for your actions.

SUPERVISION

Supervision involves working with people, and a major responsibility of a supervisor is

production. A good supervisor knows how to get a job done by getting the most out of personnel. As a word of caution, however, the drive for production must be tempered by consideration for the human element. People are not machines. The supervisor who treats them as such finds that no amount of pressure will permanently increase their rate of production. While striving for a high level of production, a supervisor wants people to produce willingly and to show an interest in their work. If you have had any supervisory experience, you are no doubt aware that the job of a supervisor is not as it sometimes appears. The following discussion will give you an idea of some of the major factors involving a supervisory position.

SUPERVISORY DUTIES AND RESPONSIBILITIES

Specific duties and responsibilities can be listed for a specific position only. However, here are some that are typical.

- Getting the right person on the job at the right time
- Using and placing materials economically
- Safety, health, and physical welfare of crew members
- Keeping morale high
- Maintaining quality and quantity of work
- Preparing records and reports
- Maintaining discipline
- Planning and scheduling work
- Training your crew members
- Procuring the tools and equipment necessary to accomplish the work satisfactorily
- Inspecting, caring for, and preserving tools and equipment
- Giving orders and directions
- Maintaining liaison with other units

- Checking and inspecting jobs of crew members
- Promoting teamwork
- Maintaining good housekeeping on the job
- Keeping operations running smoothly and efficiently

EARNING RESPECT

Respect must be earned. You cannot win it by flattery, apple polishing, throwing your weight around, avoiding issues, or striving for popularity. In supervising your crew, create an atmosphere of courteous and helpful direction. The less noise you make, the better the results. There is no room for the "Do as I say, not as I do" approach. In today's technical and ever-changing Navy, the need is for personnel who have intelligence, technical know-how, leadership ability, and set a good example. Good supervision produces a smooth running organization; poor supervision creates confusion, dissatisfaction, and dismay.

COMMON MISTAKES

Your first days as a new supervisor are the most important. Your crew will be watching to see how you react to your new responsibility. Your superiors will be observing you too. This is the time to avoid some of the more common mistakes made by supervisors. Learning what NOT to do is often as important as learning what to do.

"New broom" tactics are out! It is not unusual for an inexperienced supervisor to go into a new job with the idea that "things are going to be different around here." Try not to make a big showing, or let it be known that you did not like the way the last supervisor operated. If so, you have overlooked a psychological factor called "resistance to change." Some people fear and resent change. It is better to let your crew know that change can wait for now. After getting your feet on the ground, you can make changes gradually.

Do not make promises to gain your crew's friendship and support. Even a hinted or implied promise can sometimes be dynamite. For example, statements such as "if you do this job right, you may get a little time off" can get you in trouble quick. You could be overruled by higher authority. Besides, doing a good job is what everyone is being paid for already and should be

its own reward. It should not require bribes or additional compensation to get people to do what they are supposed to do.

Avoid dictatorial practices; they are fiercely resented. A dramatic display of authority during your first days on the job will be particularly noticed.

Playing favorites, being partial to former friends, ignoring the more timid of your crew members, and assigning the best jobs to a chosen few will rapidly break down the morale of your crew.

Careless remarks, which would normally go unnoticed if they came from one of the crew, take on new significance when they come from a supervisor. You must carefully weigh your remarks when members of your crew are listening.

Failure to delegate work and fearing to trust subordinates are common failings of a new supervisor. The end result is you become so backlogged with work that you bottleneck the entire unit.

When you make a promise to have a job ready for inspection at a certain time and you are unable to keep that promise, accept the blame yourself. There may be a good reason for your inability to keep your promise or the fault may lie with one of your subordinates, but the important thing is for you to accept the responsibility and not pass the buck. Passing the buck when something goes wrong is a sure way to lose the respect of your crew. And above all, do not lose your temper in front of crew members. You must master yourself before you can control others.

THE FINE LINE

As supervisor, you must draw a fine line in your relationship with your crew. Do not assume false dignity; but the old relationships that you used to enjoy may no longer be appropriate. Drawing this fine line is the most difficult part of being a new supervisor, but it must be done. As a first class petty officer and project supervisor or crew leader, you may have a difficult job in drawing this fine line, particularly when on battalion duty. You wear the same uniform and may even eat and sleep in the same areas as your subordinates. You may also attend the same clubs; however, you must ensure that your subordinates understand that your general conversation in the relaxed atmosphere of the club and your comments on the job carry different weights and have different values. This does not mean that as an off-duty supervisor you are free to act the

opposite of the way you act on the job, but it does allow you to relax somewhat. To maintain balance, ask your crew for advice and help rather than give the impression that you know it all. Let the crew members know that you have confidence in them; maintain a friendly but conservative attitude; be impartial; be consistent; and set a good example.

DISTINGUISHABLE LEADERSHIP AND SUPERVISION SKILLS

A private survey of the Navy's middle managers, junior officers, and senior petty officers found there are 16 factors that distinguish an average performer from a superior performer. They are called competencies. There are 16 competencies, which have been proven capable of distinguishing between effective and ineffective leadership performance. Some of the more important concepts are discussed below.

THE CONCERN FOR EFFICIENCY AND EFFECTIVENESS

The concern for efficiency and effectiveness should be high on all senior petty officers' priority lists. Training is the key to meeting this obligation. But before training can be effective, the individuals responsible for training should have a firm grasp of the material they will be teaching.

A common pitfall is the complete disregard for setting goals and performance standards. At times, tasks may seem insurmountable. However, it should be emphasized that through realistic goal setting and meeting performance standards, most tasks can be handled with ease. During the course of a project, the trainees should be encouraged to use this technique. Allowances should be made in task assignments for decision making on the part of the trainee; this encourages junior members to take the initiative in accomplishing tasks.

In the attempt to maintain an efficient and effective organization, communication has been identified as another problem area. This area is often overlooked at the time task assignments are being made; often the supervisor does not relay instructions clearly and concisely enough. This can result in a lack of understanding, and subsequently, a job not completed, a poorly completed section of a job, or even damage to major items of equipment.

Training

Leaders have a responsibility to train people in their present duties and for future duty responsibilities. Most jobs are usually performed adequately, but they can often be performed better. Items of equipment are constantly changing, and people must be trained to operate them. Newer people in the unit must be instructed in the proper execution of their duties. Through effective training, the potential of your people can be increased substantially.

To be effective in training subordinates, you must understand the learning process. One outstanding characteristic of people is that they have the ability to learn throughout their lifetime. They learn continuously from the time they are born until they die. To understand the concept of learning better, it is important to analyze what happens to the person. One learning experience may change a person's way of perceiving, thinking, feeling, and way of doing something. Learning can be defined as a change in behavior as a result of experience. The behavior may be physical and overt, or it may be intellectual or attitudinal; it may not always be noticeable. A leader should understand these factors and apply them during the training program. When one or more of the four learning characteristics listed below are stimulated, the individual will learn.

1. Learning must be purposeful: To the individual, one's needs and notions must be satisfied, then the learning process will be effective. If instructors are aware of this fact, they can seek ways to relate learning to the student's goals.

2. Learning comes through experience: Learning is an individual process. The instructor cannot do it for the student. The instructor cannot pour knowledge into the student's head. The student can learn only from that which is experienced.

Learning and knowledge cannot exist apart from the individual. A person's knowledge results from experience. And no two people have had identical experiences.

Although all learning is by experience, it can take place in different forms and in varying degrees. Some experiences may involve all or the majority of a person's senses; other experiences may involve only one or two senses, such as hearing or seeing. The leader is faced with the problem of providing meaningful, varied, and appropriate experiences.

Learning a physical skill requires actual experience in performing it. An individual will never learn how to install air-conditioning equipment effectively unless the work is actually performed by that individual.

Mental habits are also learned through practice. If a person is to use sound judgment and solve problems well, then this person must have a general awareness of the principles involved in solving realistic problems. Once these principles are learned and followed continually, experiences in which sound judgment has been exercised will become more and more evident.

3. Learning is multifaceted: While learning the material at hand, students may be learning other things as well. They may be learning cooperation and group dynamics. They may be developing attitudes about the Navy, good or bad, depending on what they experience. Under a skillful instructor, they may even learn self-reliance. The list is endless. This learning is sometimes called incidental, but it may have a great impact on the development of the students.

4. Learning is an active process: Students do not soak up knowledge the way a sponge absorbs water. The instructor must present the material in small bits, testing to see if the material is being absorbed by the students as anticipated.

To check the student's progress, use methods of testing as dictated by the subject matter. The Navy classifies subject matter into three types: knowledge, skill, and attitude.

Knowledge-type subject matter is taught to build up a storehouse of useful facts, principles, theories, and so on. It is usually presented in a formal training situation.

Skill-type subject matter (mental or physical) is taught to help the student acquire the ability to perform the assigned jobs with ease, speed, and precision. The teaching approach in this situation is quite different from a knowledge-type instructional situation. The presentation of knowledge-type instruction is usually given first, followed by skill-type instruction.

Attitude-type subject matter is selected and taught to create proper feelings, understanding, respect, and so forth. Safety and military courtesy are examples of attitude-type subject matter. It can be organized in the same manner as knowledge-type subject matter.

To measure attainment or progress, administer achievement tests. If the material to be tested is knowledge, then a written test would be the most

effective way of measuring progress. For skills, the performance-type test, which measures manipulative and mechanical skills as well as knowledge, is the most effective way of measuring students progress. However, attitude tests present other problems. There is no way to look inside the students' heads to see what they may be thinking, so the most effective way of measuring progress is by personal observation.

Knowing Your Job and Crew

Your job is likely to vary with each deployment of the battalion. If the principal mission of the battalion is to construct housing, you may be in charge of a crew installing interior piping. On another assignment, the mission of a battalion may be to install portable distillation plants, including the water distribution system. On some assignments, it may be necessary to install refrigeration systems. On most assignments, it is necessary to set up a mechanical repair shop. You may be in charge of a crew assigned to carry out one or more of these jobs.

To carry out the job properly, you must know exactly what is to be done, the deadlines for the job or portions of it, who will be your supervisor for the job, and the relationship of this job to other jobs or projects. You will need to plan your part of the job with respect to materials and scheduling. Unless you understand lines of authority, the materials and equipment required, the limitations of the equipment, and the capabilities of your crew, you are likely to have trouble in meeting your responsibilities.

Unless you thoroughly understand the job to be done, it is not likely that you can do a good job. It is obvious that a good supervisor needs to know the strong and weak points of each crew member. You need to know your crew to make intelligent decisions about assignments, needed training, and recommendations for advancement in rating, among other things.

When you learn that new people are being assigned to your crew, learn what you can about them. Ask to see their records, talk to them when they report, find out what they have done and like to do, and finally, observe them closely in various work situations. You will soon learn what type of people they are and know their capabilities.

Setting Goals and Performance Standards

Effective groups are successful groups. The effective unit (and the effective individual) is one

that expects success. The gunnery crew of a ship that sets out to win the gunnery championship of its division will work vigorously toward that goal only if it is getting somewhere and has a fair chance of winning. If the crew members are convinced that it is impossible to achieve this goal, they will not really try. The unit will be ineffective. The unit that expects failure will be depressed, erratic, and without zip—and likely to experience failure.

When the goal is realistic and within reach, groups will work hard. If the coach of Short Pump State College tells the team of small but well-trained football players that they are expected to beat the number one team in the country, it is unlikely that much work from the team will occur. Such a goal is unrealistic. Since the coach's goal is too high, no member of the team has any real hope of success. But if the goal is to score on the number one team, there will be more enthusiasm. They will work equally hard to get ready for a game next week with a neighboring team that has beaten them 10 times in the last 16 games. That is a goal that might be reached.

Now, if the goal is to beat another nearby college team that has not won a game in 7 years, the team is not likely to work hard either. Since it is such an easy goal, it is not a challenge.

If the group is to work toward a goal with energy and commitment, it must be a realistic challenge. When goals are set too high, the group will not function well. Frustration, unhappiness, and resentment are the likely results. Goals that are set at a realistic, challenging level promote good morale within the group.

The supervisor should be concerned with the performance of the crew. Performance will hinge on realistic goals being set and acceptable standards being established. These standards should be set at the outset of the project, so the crew is aware that their work will be measured against some standard and that the project is of concern to the supervisor and the command. When made aware of these facts, the crew will tend to put forth its maximum effort in the accomplishment of the task.

Individual performance and satisfaction result from the interaction of four basic elements:

1. The individual: The person's motives and skills.
2. The individual's manager: The expectations and behavior of the person's manager—the managerial style used.

3. The individual's job: Tasks that must be performed by the person as part of the job.

4. The individual's work center or command: How the person views the climate and structure of the work center or command.

When you, as supervisor, are able to make the elements fit and work well together, the workers' performance and satisfaction will be high. Conversely, when these elements do not fit together, but instead conflict, jobs will not get done and work satisfaction for the crew will be low.

Taking the Initiative

At this point in your career, you will supervise crews and platoons. The young men and women of your organization are very perceptive. If you obey orders and regulations in an unconcerned fashion, the chances are your orders to your people will be received and administered in the same manner.

When the crew leader is in the process of giving an order, how often have you heard the statement, "The chief said. . . ." By making such a statement and without realizing it, the crew leader relinquishes all authority to the chief who gave the order originally. Not all orders that you will be required to follow in the Navy will be to your liking; however, it is your responsibility to accept them and administer them as if they were your own.

As the supervisor, you should take the initiative and accept the responsibility—it is yours! If you respond in an unconcerned fashion, the result could be costly. In time, the crew will sense your lack of concern over the project and will not be concerned about the time it takes to carry out the task. In regard to material, your lack of concern in this area will also affect the crew's concern for conservation of material. The safety of your crew, as well as other personnel in the area, will be jeopardized through halfhearted enforcement of safety regulations.

You should adopt the attitude that the buck stops with you. This will have to be more than a mental process; you will have to demonstrate these actions by becoming a self-starter. You should anticipate situations rather than react to them. You should start new actions and plans without being told, and you should be resourceful and persistent. Junior members of your team will sense this attitude and will be more likely to follow suit.

Communicating Effectively

When old friends talk to each other, they usually communicate easily and naturally. They may use only incomplete sentences or gestures. Sometimes a single word or a raised eyebrow conveys all the meaning necessary. They are able to make themselves understood because they communicate in an atmosphere of mutual understanding and trust; they are receptive to each other's thoughts and opinions.

We take for granted our ability to communicate with others, for speaking and conversing are integral parts of our lives. Yet communicating in the work situation can be a real challenge to you, as a supervisor. When you give a simple order to a subordinate or listen to a suggestion from a subordinate, you face communication barriers that rarely exist between old friends.

Although the obvious tools of communication are words (written and spoken) and pictures (TV, maps, drawings), this chapter deals mainly with the verbal and nonverbal communication process between two people.

Effective communication is more than sending a message. Effective communication occurs when the receiver accurately understands the message.

The effective person-to-person communication process has three steps.

1. The sender encodes and sends a message.
2. The listener receives and decodes the message.
3. The sender makes sure the receiver correctly understands the message by asking for feedback.

To send a message, you select symbols or words that convey your intended message to the receiver (encoding). At its basic level, communication is achieved through the use of simple oral and visual codes. Your ideas are communicated only when the words are combined in meaningful, whole sentences. Each part of this code is vital to effective communication. You must select your words carefully to convey messages your listeners can understand.

Facial expressions, hand gestures, and body motions form other communication signals. These nonverbal signals often convey more information than the verbal codes. With these nonverbal signals, we consciously or unconsciously reveal our emotions, feelings, and attitudes.

The effective communicator always remembers one basic rule: communication succeeds only in relation to the reaction of the receiver. Communication takes place when the listener reacts with understanding and makes behavior changes accordingly.

The listener receives and then decodes the message from a personal frame of reference, likes and dislikes, and particular needs. You can help to translate your message accurately if you assess the receiver's background, experience, and education before you send your message. You then increase your chances of communicating with words and feelings that have meaning to your receiver.

You can determine if your listener accurately understands your message from the information relayed back to you. This feedback of information takes many forms. A person may state, "As I understand you, you want me to. . . ." Or the person may express agreement or disagreement with what you say. Wandering glances by the person with whom you are talking may express confusion, impatience, or boredom. An affirmative or negative nod of the head provides meaningful feedback. You can learn much about your communications by observing the reactions of your receivers.

Your challenge is to be sufficiently perceptive to detect this feedback. You can then ask yourself the following questions:

- Am I accurately sending my intended message?
- If not, how can I adjust my transmission to obtain the desired results?

Listening is another area where communication breaks down. Hearing is not listening. A person hears, often without listening, whenever sound waves strike the eardrums. Hearing, a physical experience, is only a step in the listening process. Comprehending and remembering are the others. Not until a person comprehends and remembers what is heard can the person be said to be listening. Listening is an active process that engages a person's reasoning and thinking processes. To listen, a person must put energy and effort into the listening process. One must concentrate.

By definition, concentration is "close mental application" or "exclusive attention." Occasionally, stories circulate about some genius who can simultaneously be reading a book,

listening to someone talking, hearing the president speak on the radio, and abstracting the important ideas of each. Few people can match this performance. In fact, most people must work at focusing their attention on even one subject for any length of time.

The behavior of the mind can be compared to the flow of a river. A river meanders, finding and following the course of least resistance from the mountain to the sea. Every navigable river, however, has a safe channel. The captain who wants to take a ship up and down the river keeps the ship in this channel. Like a river, the human mind tends to wander, but the objective listeners keep their attention in a mental channel, the channel of concentration. Whenever listeners allow their minds to stray, they let the current of the spoken ideas in the channel pass them by. Their attention may get back into the current, but it can rarely catch up with the speaker's ideas. What can people do to channel their attention? The answer lies in forming good listening habits.

Listening effectively is not a gift; it is acquired through practice and hard work. Anyone who wants to become a better listener can do so by practicing the following rules:

- Get ready to listen.
- Listen to understand rather than to refute what is said.
- Take responsibility for comprehending.
- Control emotions.
- Be mentally agile.

The successful communicator realizes that person-to-person communication has both verbal and nonverbal signals. Words must be carefully selected, using concrete ones, where possible. A good communicator knows the message not only must be sent but also the listener must accurately understand the intent of the message. This encourages the two-way communication process for a mutual exchange of facts, feelings, and ideas. Messages that are sent back are listened to, then worked on to overcome the barriers to two-way communication by building a helpful and supportive work climate.

If a communication problem does exist for you, more detailed information may be obtained from the training manual *Human Behavior*, NAVEDTRA 10058-C1.

USE OF INFLUENCE

An essential tool of leadership is the knowledge of human nature. If you understand the needs that direct and influence behavior, you are better equipped to fulfill your leadership responsibilities. You are then better able to understand both yourself and your crew, for you are both subject to the same basic needs.

Supervisor's Influence

You, as a supervisor, must realize when a person's needs surface, that person will take whatever action is necessary to satisfy those needs. Knowledge of human behavior can help you considerably in your leadership and supervision role.

Each person is different. Although each person has unique needs, people have many needs in common. People, as they grow and develop, are subject to similar experiences in the family, the school, and the society in which they live. Therefore, despite wide individual differences, people within our culture display certain common characteristics.

Identifying and classifying the needs that influence human behavior according to their relative importance are important tools in understanding human behavior. We need a classification simple enough to be practical yet broad enough to cover observed behavior. At best, a classification cannot be all-inclusive because some needs defy classification in neat categories and the comparative value of needs fluctuate.

All people have five common needs. These needs may be pictured on a triangle, or pyramid, with the basic needs lying at the base with the increasingly more complex needs layered toward the top. Starting from the bottom, the needs arranged in order of their relative importance are (1) survival, (2) safety, (3) social, (4) ego, and (5) growth.

First, you must understand the survival needs that appear in humans and are shared with all animals. People's need for food overshadows their other needs when they are hungry. The basic survival needs for food, air, and water are the most urgent, and satisfaction of them cannot usually be postponed. Safety requirements push social and ego needs (needs for friends and self-esteem) into the background. Take the example of a person who is looking for a job; the security need for a job will most likely dominate that

person's behavior. The belonging and self-esteem needs do not influence the person's behavior to a great extent until he has a job and has met security needs.

People's higher needs to belong (social) and for self-fulfillment of their potential (growth) arise only after their physiological, safety, and security needs are satisfied. The lower needs normally are easier to satisfy, but the satisfactions are less pervasive. Higher needs, however, can be disregarded more easily; but when satisfied, they bring a greater sense of well-being. In general, survival, safety, and belonging needs are similar but self-esteem (ego) and self-fulfillment (growth) needs vary more from individual to individual.

When trying to persuade or sell an idea by recognizing an individual's needs for esteem and self-growth, you should remember to always restate the individual's needs, because once satisfied, those needs cease to influence that person's behavior.

In the process of influencing the behavior of your crew, try to gain commitments to organizational goals, traditions, and values. These objectives may be obtained by making others feel strong; for example, by delegating authority and responsibility to frontline subordinates and by clearly communicating with them. Keep them fully informed by providing timely, up-to-date information. Other important aspects are stating reasons why such a task must be done, providing time limits, and setting a personal example.

Self-Control

As you have progressed up the ladder, you have had considerable influence on a large number of people. Just as you are constantly rating your people, they are constantly rating you. Regardless of your actions, good or bad, some people will model themselves after your example. As their leader, you should maintain self-control even under the most stressful conditions. Modeling desirable behavior is important!

Team Building

The skillful use of the team building concept will promote a spirit of teamwork and cooperation within work groups. You can do this by effectively communicating with your subordinates, with workers of other groups, and with everyone concerned, so they will all cooperate in the completion of assigned tasks.

Development of Subordinates

How often have you found yourself in a position where you are unable to go on leave or even take a day off? In a sense, this is an example of poor supervision practice. Through the years, you have obtained a great deal of knowledge and skill. You must transfer this to your subordinates, along with an example of how the jobs are to be done. This is done by providing your subordinates with a variety of the right tasks, training opportunities, expertise, and resources. It should be expected that your superiors will provide similar opportunities for you.

One area in the development of subordinates that is often overlooked is in teaching them how to make decisions.

The bulk of most people's lives is composed of routine matters that can be satisfactorily disposed of by snap judgments or by following routine procedures. Be alert, recognize the exception. Recognize the situations that call for applying the decision-making process.

1. THE NEED FOR A DECISION—IS THERE A PROBLEM?

Poor decisions often result because we fail to recognize the problems and we act on impulse. The first step in sound decision making is the ability to recognize problems requiring solutions instead of routine handling.

2. WHAT IS THE SITUATION?

Pertinent facts about a situation are the basis for making a sound decision. Situations do not just happen. They come about for various reasons: something different, new, or unplanned occurred to change the situation. Your job is to ask, What happened? What caused the problem? What are the circumstances? The more relevant information you gather, the better chance of a sound solution.

3. THE NATURE OF THE PROBLEM—PROBLEMS AND THE PRIORITY THEY ASSUME.

Sometimes you may identify the symptoms of a problem situation and fail to recognize the deeper and underlying problem. As a decision maker, you must not only recognize the problem, but you must also identify and treat the underlying cause that prompted it in the first place.

4. WHAT ARE THE ALTERNATIVE COURSES OF ACTION?

As you analyze the facts gathered that help to explain the situation, new and different ideas begin to develop. There is no formula for analyzing data or ideas to say which is the best; this is where your initiative, creativity, and imagination are challenged.

5. WHAT WILL BE THE CONSEQUENCES?

At this point in the decision-making process, you need two columns for writing down the points for and against each alternative course of action. Ask, What will happen if . . . ? Does this course of action take care of A, B, and C possibilities? Include long- and short-range advantages and disadvantages. When you do this seriously and honestly, you have made a good analysis of the various alternatives.

6. WHAT ALTERNATIVE IS TO BE CHOSEN?

You are now ready to make the decision with good reason to hope that it will be a sound one. This step is often the simplest and easiest of the whole process.

7. WHAT IS THE PLAN OF ACTION AND SCHEDULE FOR CARRYING OUT THE DECISION?

Now that you have made a decision, your next step is to take action. You must not only clearly state your decision but also give guidance to those who carry it out.

8. HOW WELL HAS THIS DECISION WORKED OUT IN PRACTICE? IF IT FAILS, WHAT ALTERNATIVE CAN BE TAKEN?

Consider changing your course of action if you learn some important new facts that appear to alter the situation. Consult in advance all those who are to be affected by the decision. You need their cooperation. No decision is any better than the people's willingness to carry it out. Their cooperation and understanding are essential if you must redirect your course of action.

ADVISING AND COUNSELING

Advising is helping people take steps to correct problems. This is done by providing information about functions, procedures, opportunities, and alternatives for the actions that might be taken.

Counseling is helping individuals explore, understand, and discover solutions for problems. You should encourage the individuals seeking help to find different ways of solving their problems.

A critical technique to motivating, developing, training, and appraising the performance of your subordinates is counseling. Many supervisors either shy away from counseling subordinates or bungle the job because they do not understand the true nature and function of this important responsibility. When counseling, you need to realize that you cannot change a subordinate's attitude directly. You must get the individual to change his or her own attitude.

The key to counseling is to find out the motivation behind certain behavior. The objective is to change the attitude and behavior of the subordinate by having him or her recognize the problem and the thinking that led to it. Criticize the performance, not the person. Suggest the person think about the problem and find ways to solve it. Counseling should be used for career-development planning, training, and accepting changes; counseling is not just for performance problems.

Be sure to listen and use questions that motivate the subordinate to examine himself or herself. Wait for answers to your questions; don't jump in when there is silence. To ensure that this process works, follow up. Look for evidence of change and base your next session on the rate of change, prior questions discussed, and indications or resistance to change.

To advise and counsel subordinates successfully, you must develop both positive and realistic expectations.

Positive Expectations

Leadership is having a positive outlook regarding future expectations, and it deals with the way you think. It involves believing and trusting in your subordinates' basic worth and abilities. It also means having positive feelings about your subordinates' growth and development. When using this skill, you must have a strong belief that others are fully capable of doing good work when given a chance.

Realistic Expectations

Realistic expectations also deal with the way you think about people. It is realizing that instructions may not always be followed or carried out effectively by others. In having realistic expectations, you must be aware of the shortcomings of people.

Understanding

Once a subordinate's problems are identified, you can employ the element of understanding to help them see the reasons for their problems. Understanding is a way you can respond in a time of need to help your subordinates deal with their problems.

CONCEPTUALIZING

Conceptualizing is important because it helps you to determine which element of leadership you should apply to any given situation. To do this effectively, you must have the ability to conceptualize a situation.

Conceptualizing is being able to view a situation, identify what is going on, sort through available facts, and draw conclusions. In other words, it is seeing the big picture of what is happening. Remember, you are a significant part of this picture. Use it to advantage!

INSPECTIONS

Maintenance inspection/service checkpoints for various types of facilities and equipment are provided in *Inspection of Shore Facilities*, NAVFAC MO-322, volumes 1, 2, and 3 and *Preventive/Recurring Maintenance Handbook*,

NAVFAC P-717.0. As a supervisor and a craftsman, you should use the checkpoint guidelines to perform preventive maintenance inspections (PMI). The purpose of these publications is to provide a guide for developing and implementing an effective and efficient PMI system. The goal of the PMI system is to maximize the useful life of facilities and equipment and to minimize costly breakdowns and repairs. The steps in establishing a sound and effective PMI system are as follows:

1. Prepare a comprehensive inventory of all facilities and equipment that are a public works maintenance responsibility or a battalion maintenance responsibility.
2. Review manufacturers' operational manuals and maintenance manuals to determine the necessary routine maintenance inspection/service requirements.
3. Establish a formal PMI schedule that includes the details of inspection/service to be accomplished, the frequency of inspection/service, and the standard time required to perform inspection/service for each inventory item.
4. Inspect facilities and equipment using the appropriate checkpoint guides and report on the condition of each element inspected.
5. Periodically review the PMI system to assure work is accomplished as planned, that scheduled frequencies are reasonable, and that facilities and equipment are neither over maintained nor under maintained.

REFERENCES

Human Behavior, NAVEDTRA 10058-C1, Naval Education and Training Program Management Support Activity, Pensacola, Fla., 1989.

CHAPTER 3

FACILITIES MAINTENANCE MANAGEMENT

The information in this chapter pertained to chief petty officer occupational standards and has been removed. This subject matter has been revised and placed in *Naval Construction Force/SEABEE Chief Petty Officer*, NAVEDTRA 10600.

CHAPTER 4

BLUEPRINT READING AND TECHNICAL DRAWINGS

Learning Objective: Identify the graphic symbols and diagrams used on prints; analyze the types of diagrams and prints used by the Utilitiesman; assess the uses of specifications, as they relate to construction; and recognize the importance of accurate recordkeeping.

Blueprints, sometime called prints, are reproduced copies of mechanical or technical drawings. Drawing and sketching are the universal language used by engineers, technicians, and skilled trades personnel.

Your ability to read blueprints or blueprint reading is the means by which you interpret the ideas of others expressed on the drawing, whether the drawing is an actual blueprint or not.

This chapter has been developed to give you some insight into the preparation and use of blueprints. By carefully studying this chapter, you will gain the knowledge necessary to become skilled in the use of drawings and sketches.

DEVELOPMENT OF CONSTRUCTION DRAWINGS

Drawings are generally categorized according to their intended purposes: preliminary drawings, presentation drawings, shop drawings, and working drawings.

A building project may be broadly divided into two major phases: the design phase and the construction phase. First, the preliminary drawings are prepared during the design phase. They are prepared by the designer or by the A and E firm (architects and engineers) to promote the building development. The preliminary drawings are used for exploring design concepts between the designer and the user (customer), making material selection, getting preliminary cost estimates, and as a basis for preparing the finished working drawings.

During this phase, the presentation drawings that are developed show the proposed building or facility in an attractive setting in its natural surroundings at the proposed site. Since these drawings are actually used to sell an idea or a design, your only contact with such drawings will be as a cover sheet to a set of construction drawings.

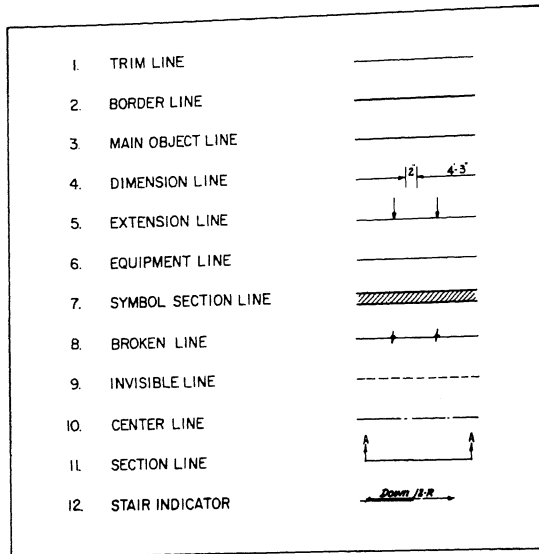
In the second phase, after approval has been given for construction, shop drawings and working drawings are developed. Throughout your career, you will hear these drawings referred to as construction drawings, prints, or plans. Basically, these terms are all correct; they can be used interchangeably.

As mentioned earlier, the construction drawings are developed from the preliminary drawings. With the collaboration of the designer or the architect and the engineer, both the materials to be used and the construction methods to be followed are decided. The engineer determines the loads that the supporting (structural) members will be required to bear and designs the mechanical systems for the structure; for example, heating, power, lighting, and plumbing.

As a crewmember or a supervisor, you will find the construction drawings, the specifications, and the bill of material your chief source of information during the construction of the project.

BLUEPRINT READING

There are a number of reasons for having construction drawings and why you should have the



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Figure 4-1.—Construction drawing lines.

ability to read and interpret them. Imagine using only written instructions for the construction of even a small building. It would take volumes of written material. Having to try to understand and visualize all the details involved in the construction would present a very difficult problem for anyone.

For this reason, prints are used to express the ideas easier and faster. They are also used by the supervisor to monitor the progress of construction.

From these drawings, the craftsman must be able to interpret and perform the work, follow directions, and visualize the work alone. You should be capable of reading the prints and passing along the information contained on the drawings. As you should be able to see now, the Utilitiesman who is unable to read and interpret prints would require extra help, causing an unnecessary personnel drain.

BLUEPRINT LANGUAGE

There are various ways that a blueprint tells you what is to be done. Since the written word could be confusing and take up too much time and space, other means of getting the ideas across to the craftsman were developed. These means include various types and weights of lines, symbols, abbreviations, and many other methods of giving dimensions and working directions.

TYPES AND WEIGHTS OF LINES FOUND ON DRAWINGS

The main types of lines the Utilitiesman should be able to read and understand are the main object lines, dimension lines, extension lines, equipment lines, broken lines, and crosshatched lines. (See fig. 4-1.)

Below is a partial listing (and definitions) of the lines the Utilitiesman should be able to recognize readily.

Trim line. A light, continuous line along which the tracing is trimmed to square the sheet.

Border line. A heavy, continuous line that outlines or borders the drawing. The border line expresses the fact that the drawing is complete within this lined border.

Object line. A heavy, unbroken line used to show visible outlines or edges that would be seen by people looking at the article, house, or building. This line is one of the most important because it outlines the main wall lines on plans and sections. It shows clearly the important parts of the construction and emphasizes the outline of the elevations.

Dimension line. A light line drawing outside the structure or detail to show the distance between two points. This line is drawn between extension lines with an arrowhead on each end. Between the arrowheads, the distance will be given, either at a break in the line or just above the line. On some drawings the scale and the distance between the two points may not agree; in that case, the distance will be given in a dimension line.

Extension line. A line use with dimension lines and that touches the dimension line. The line will extend out from the edge or the point at which the dimension is to be determined.

Equipment line. A light, continuous, unbroken line used to show the location of equipment, such as water chillers, boilers, and galley equipment. This line is used to allow the Utilitiesman to install the necessary piping in the proper location during rough-in work.

Symbol section lines. These lines are generally solid; although for certain conventions, dotted lines of the same weight may be used. Section lines, evenly spaced, are used to shade surfaces shown on a drawing and by these means indicate the material used. Material section lines are standardized to a certain degree, but you will find some variations. A set of working drawings using these symbols would have a symbol schedule key showing the various materials in that particular

set. This schedule is usually placed near the title box on the plan of the first floor.

Broken line. A line with wavy breaks in it, at intervals, used to indicate that parts have been left out or that the full length of some part has not been drawn. This line will be found a lot in detail drawings, where only a section of the object is to be shown.

Hidden line. This line is made up of a series of short dashes and is used to indicate a hidden or an invisible edge or edges that are hidden under some other part of the structure.

Center line. This line is made up of alternating long and short dashes and is used to indicate the center of an object.

Section line. A solid line that has arrowheads at each end that point in the direction in which the section is to be taken. This line tells just where the section line has been cut through the wall or building. The sections are indicated in most cases by the letters A-A, B-B, and so forth, although numbers are sometimes used. Do not overlook these section lines on a plan. To obtain a clear picture of the construction at the particular point indicated, always refer to the section detail called for by the letter or number.

Stair indicator line. A solid line with an arrowhead indicating the direction of the run. For example, Up 12-R means that there are 12 risers from floor to floor and that the stairs go up. A riser is the vertical part of the step; the flat part on which one steps is the tread. In most cases, the floor plan will only indicate the run of stairs half the distance between floors. For example, the ground floor will indicate a broken line that will tell you the steps continue up. The next floor plan will indicate the stair indicator line half the distance to the first floor, down.

ELECTRICAL SYMBOLS AND ABBREVIATIONS

In addition to using different types of lines, the architect's and engineer's intentions are communicated through the use of symbols and abbreviations. In the preparation of the electrical drawings, most engineers use symbols adopted by the American National Standards Institute

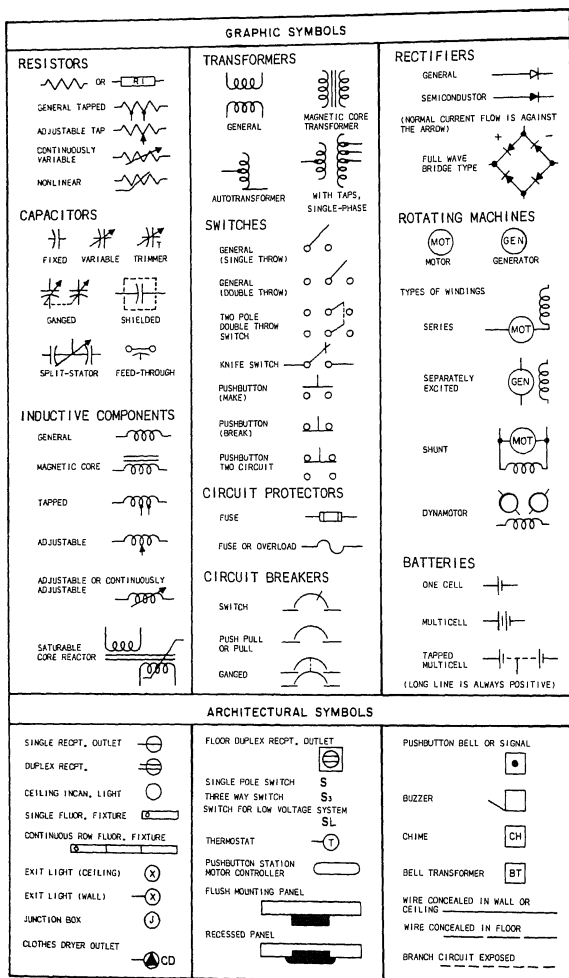


Figure 4-2.—Electrical symbols.

(ANSI). However, many engineers will modify them to suit their needs. For this reason, most drawings have a symbol list or legend. The electrical symbols in figure 4-2 are taken from the ANSI Y32.9, 1972 publication.

CONSTRUCTION DRAWINGS

With a thorough knowledge of blueprint language (symbols, abbreviations, and lines), you will be able to extract the information that is provided on the different prints. Types of construction drawings you should be familiar with are discussed in the following sections.

Plot Plan

The plot plan is the starting point for any building that is to be constructed. It shows where the building is to be placed on the plot of land or property and shows the shapes and dimensions of the plot. When the plot plan is bounded by streets or drives, such information is also shown.

The plot plan aids the Utilitiesman by showing the plot where the service taps from a main are to be connected or what route the pipe will need to be run for an underground service.

Exterior Elevation Drawings

The exterior elevation drawings show views of the finished exterior sides of the building. They show exterior trim, finish, window and door openings, roofing, and brickwork. Finished grade lines and floor lines are also shown. You may find this information helpful in locating outside wall hydrants or hose bibs.

Interior Elevation Drawings

The interior elevation drawings show views of inside wall space that contain counters, sinks, cupboards, and other special features. These drawings can be of great help in determining where to place rough-in piping for water or drainage systems in kitchens and bathrooms. The material that is to be used for walls also affects the distance from the finished wall that the through floor drainage or water supply will be roughed in to (water closets, floor drains, and so forth).

Sectional or Detail Drawings

Sectional or detail drawings are often inserted into drawings to show a specific detail. They may be a cross-sectional view of the building supports or foundation. They could be used to show story height and ceiling height. They may be used to show what floors are made of, whether they have wooden joists or some other type of construction. Any of these factors might influence the method of doing mechanical work and the kind of material that is to be used.

Floor Plan

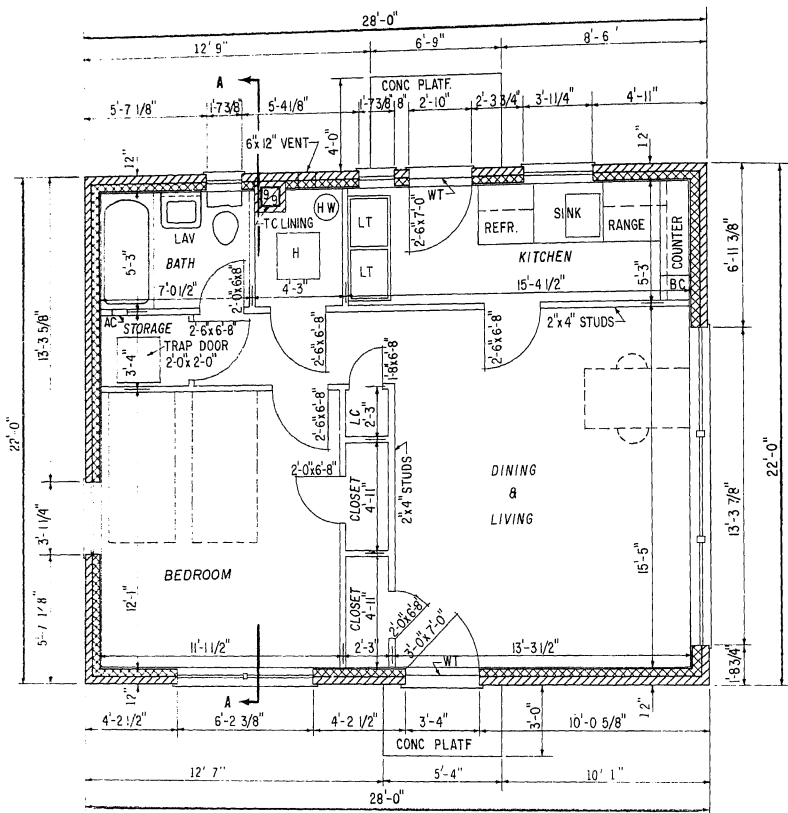
A floor plan drawing is used to show exactly what the name implies, a plan of the floor. The drawing includes the layout of all interior and exterior walls, including windows and doors. It also shows all fixture requirements. A typical floor plan is shown in figure 4-3.

All the drawings mentioned thus far are proportional reductions of the final structure. The amount of reduction depends on the size drawing desired. Dimensions in feet are reduced to parts of an inch; for example, 1 foot may be reduced to 1/4 inch or 1/8 inch. The reduction is called the scale of the drawing. If the scale of a drawing is 1/4 inch = 1 foot, a 1-inch line would represent 4 feet on the actual structure.

BILL OF MATERIAL

A bill of material (BM) is a tabulated statement of the material required for a given project. It contains information such as stock numbers, unit of issue, quantity, line item-number, description, vendor, and cost. Sometimes the bill of material will be submitted on either material estimate sheets or material takeoff sheets; each contains similar information. Actually, a bill of material is a grouped compilation based on the takeoffs and the estimates of all the materials needed to complete a structure. Usually, the takeoff sheet is an actual tally and checkoff of the items shown, noted, or specified on the construction drawings and specifications.

Most NAVFAC drawings will contain a bill of material incorporated within the drawings. But, there are times when you are directed to tabulate materials needed for a new project that has been designed in-house for cost estimating and funding.



45.515A

Figure 4-3.—Floor plan.

An example (and explanation) of the bill of material sheet is given in chapter 5 of this manual.

ELECTRICAL WIRING AND MECHANICAL DIAGRAM

As a Utilitiesman, you will be working with mechanical equipment that will require electrical connections. This will require your close liaison

with the Construction Electricians and involve you in working with electrical diagrams as well as mechanical drawings. *Utilitiesman 3 & 2*, Volume I, Chapter 3, NAVEDTRA 10660, thoroughly covered mechanical drawings and symbols. This section will discuss the electrical diagrams and symbols the Utilitiesman may use.

An electrical diagram is defined as a line drawing that shows the arrangement and/or

relationship of parts. Electrical diagrams are usually used to show how the parts of a piece of equipment or several pieces of equipment are wired together. These diagrams are similar to each other. Their names are sometimes used interchangeably, but they do have differences.

The types of diagrams with which you will be working are covered below. The short description of each should enable you to recognize the different diagrams.

ISOMETRIC WIRING DIAGRAMS

The isometric wiring diagram is not used very often in electrical work. When used, it shows the electrical relationship in multilevel buildings, between floors, or the total electrical system. In the isometric diagram, the cable and fixtures are shown only in their general location. Their exact locations are given in the electrical prints. (See fig. 4-4.)

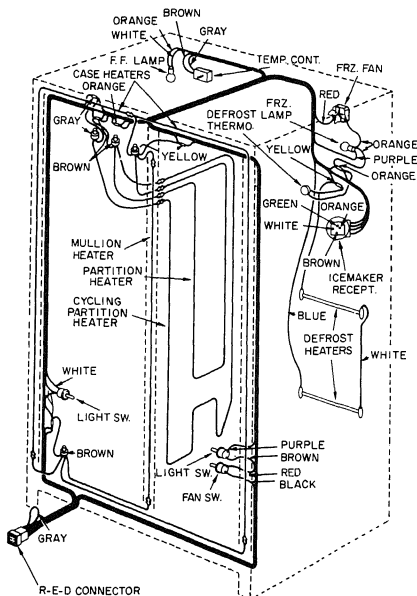


Figure 4-4.—Schematic wiring diagram of side-by-side refrigerator with automatic ice maker.

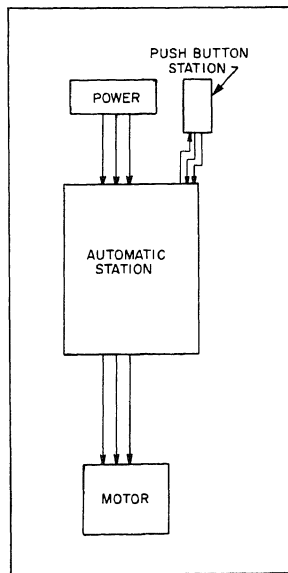


Figure 4-5.—Block diagram.

BLOCK DIAGRAMS

A block diagram is a simple drawing showing the relationship of major parts of a system. Figure 4-5 shows a block diagram of a motor control system. You can easily see why it is called a block diagram. The parts or components in any block diagram will be shown just as they appear in this drawing, as blocks. They are then connected by a line or lines that show the relationship of the parts. The internal connections of the components are not shown in these drawings. The blocks are simply labeled to show what each represents. These drawings would be of little help for troubleshooting.

WIRING DIAGRAMS

The wiring diagram, which is like a picture drawing, shows the wiring between components and the relative position of the components.

Figure 4-6 shows a wiring diagram of the same motor control system shown by the block diagram. You can see that instead of blocks being used to show components, a picture of the component is used. You can also see that the lines used to show the wiring are marked with numbers or letter-number combinations. Lines L1, L2, and L3 are incoming power leads, and the diagram shows which terminals they are connected to in the starter. Wiring diagrams are often used along with a list of repair parts and can be used to do some troubleshooting.

CONNECTION DIAGRAMS

Figure 4-7 is a connection diagram. It makes use of diagram symbols instead of pictures to show components. It also shows all the internal and external circuit connections, and these can be read and traced more easily than on the wiring diagram. In the connection diagram, the components are still shown in their relative positions. This diagram can be used to help you connect all the wiring and trace any part of the circuit, which makes it a very valuable troubleshooting tool. It is often found inside the cover of a piece of equipment.

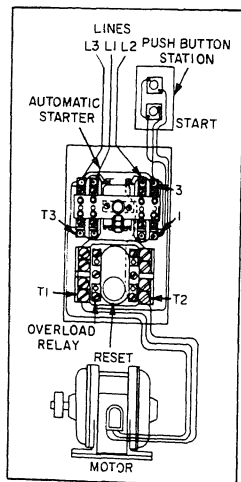


Figure 4-6.—Wiring diagram.

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SCHEMATIC/SINGLE-LINE DIAGRAMS

The schematic diagram is a drawing that shows the electrical plan of operations of a piece of equipment or component. The relative position of parts is not shown in this type of diagram. The schematic diagram, like the connection diagram, makes use of symbols instead of pictures. The schematic shown in figure 4-8 is a plan

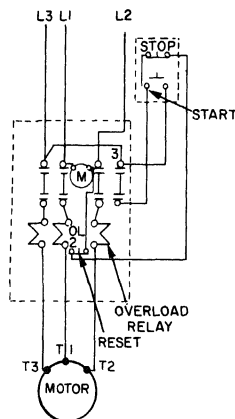


Figure 4-7.—Connection diagram.

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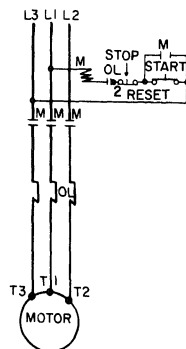


Figure 4-8.—Schematic diagram.

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of the same motor control system shown in the other three diagrams. It is laid out so the components are in line to make it easy to trace the operation. Notice the use of heavy and light lines in the drawing. In this case, the heavy lines show the main power circuit, and the light lines show the control circuit. The schematic is sometimes called an elementary or a single-line diagram. It is very useful in troubleshooting or tracing the plan of operation.

WORKING SKETCH

As you have learned thus far, the information provided in the floor plan of a blueprint is limited to what fixtures are to be installed and their locations. Diagrams that show the actual layout of the plumbing systems are provided in the mechanical section of the prints. Before you send a crew to put in a system and its components, a working sketch should be drawn translating the blueprint drawings to a usable tool that can guide a crew leader during actual installation or troubleshooting of a system.

A working sketch is a drawing made to clearly express a tasking and provide quick reference to

job requirements. It is drawn to help show actual conditions on the job, what size piping is to be installed, where connections will be made, and possibly what type of joints will be used. It should show as much detail as you can include to help your crew during installation or troubleshooting. A working sketch will usually show the work you want your crew to accomplish in a selected area, and will provide ready reference to jobsite conditions. Figure 4-3 is the floor plan of a house; it shows a bath, heater room, and kitchen. The floor plan of a structure is found in the architectural section of the blueprint package. It shows the locations of plumbing fixtures, built-in cabinets, mechanical equipment, and so forth, that will be installed as functional components of the completed facility.

Now that you have seen what the floor plan shows, look at figure 4-9. This is an isometric drawing of the plumbing system that will service the floor plan shown in figure 4-3. It lays out the system showing every detail involved in the installation but is not representative of actual jobsite conditions. From the isometric drawing you can determine planning and estimating information but not the actual locations or installation

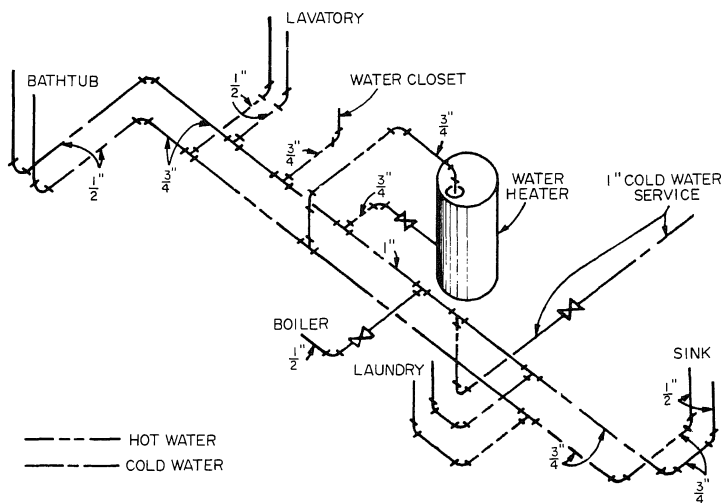


Figure 4-9.—Isometric drawing of hot and cold water piping system.

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interfaces and problems your crew may encounter during the job.

The working sketch is something a crew will have with them while working. It can show them how, what, where, and when things happen in the sequence of the job. Your first step in making a working sketch would be to draw the symbols that represent all the fixtures that are to be installed and locate them within the room. Try to draw them in the sequence of installation and include measurements. Now draw the piping system for hot and cold water, show where it comes from and where it is going. Include pipe sizes, fittings, hanging requirements, and rough-in measurements. Do the same for the sanitary and vent systems. The amount of detail you use in a

working sketch will be determined by the crew's experience, the complexity of the systems involved, and the need for interface with other trades working on the jobsite.

Working sketches are also useful to simplify complicated electrical schematics when you are installing or servicing mechanical equipment such as air-conditioners and boilers. Figure 4-10 shows the electrical symbols you will commonly find when reading electrical schematics. By understanding what these symbols represent, you will be able to translate manufacturer's equipment schematics. By drawing a simplified working sketch of this information, you will be aiding your crew in the installation and troubleshooting of the equipment.

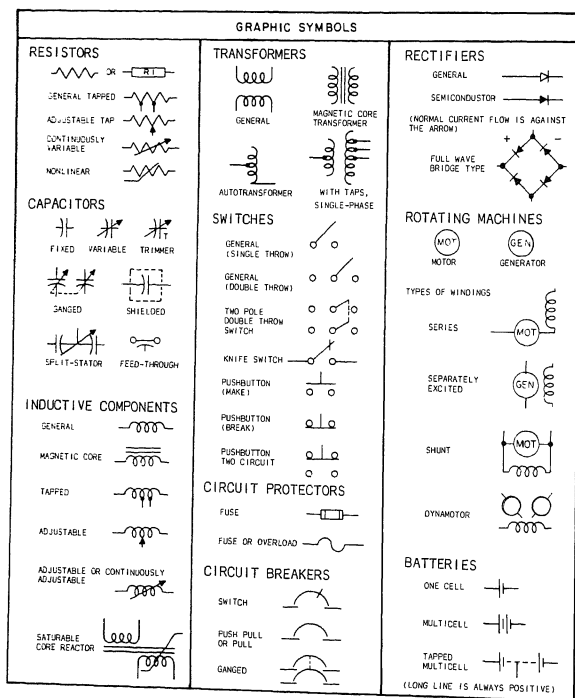


Figure 4-10.—Electrical symbols.

ELECTRONIC SYMBOLS AND DIAGRAMS

Because more and more electronic circuitry is finding its way into the Utilitiesman's world, you will be called upon to make

repairs to equipment that uses these circuits. Your ability to recognize basic circuits and their basic operation will be paramount in the repair of such equipment. Figure 4-11 shows the electronic symbols most commonly used.

ARRESTER, LIGHTNING (4)	CAPACITOR (8)	CIRCUIT BREAKER (11)	jacks normalled through both ways
general 	general 	general 	
carbon block 	polarized 	CLUTCH; BRAKE (14) disengaged when operating means is de-energized 	2-conductor nonpolarized, female contacts
electrolytic or aluminum cell 	adjustable or variable 	engaged when operating means is de-energized 	2-conductor polarized, male contacts
horn gap 	continuously adjustable or variable differential 	COIL, RELAY and OPERATING (16) 	waveguide flange
protective gap 	phase-shifter 	semicircular dot indicates inner end of wiring 	plain, rectangular
sphere gap 	split-stator 	CONNECTOR (18) assembly, movable or stationary portion; jack, plug, or receptacle 	choke, rectangular
valve or film element 	feed-through 	jack or receptacle 	CRYSTAL, PIEZO-ELECTRIC (62)
multigap 	CELL, PHOTSENSITIVE (Semiconductor) (9) asymmetrical photoconductive transducer 	separable connectors 	COUPLER, DIRECTIONAL (27) (common coaxial/waveguide usage)
ATTENUATOR, FIXED (see PAD) (37) (same symbol as variable attenuator, without variability) ATTENUATOR, VARIABLE (5) balanced 	symmetrical photoconductive transducer 	two-conductor switch-board jack 	triode
unbalanced 	photovoltaic transducer; solar cell 	two-conductor switch-board plug 	pentode, envelope connected to base terminal
BATTERY (7) generalized direct current source; one cell 		jacks normalled through one way 	twin triode, equipotential cathode
multicell 			

Figure 4-11.—Electronics symbols.

13.5.1











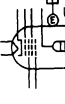


































<p>rectifier; voltage regulator (see LAMP, GLOW)</p>  <p>phototube, single and multiplier</p>   <p>cathode-ray tube, electrostatic and magnetic deflection</p>   <p>mercury-pool tube, igniter and control grid (see RECTIFIER)</p>  <p>resonant magnetron, coaxial output and permanent magnet</p>  <p>reflex klystron, integral cavity, aperture coupled</p>  <p>transmit-receive (TR) tube gas filled, tunable integral cavity, aperture coupled, with starter</p> 	<p>traveling-wave tube (typical)</p>  <p>forward-wave traveling-wave-tube amplifier shown with four grids, having slow-wave structure with attenuation, magnetic focusing by external permanent magnet; rf input and rf output coupling each E-plane aperture to external rectangular waveguide</p>  <p>FERRITE DEVICES (100)</p> <p>field polarization rotator</p>  <p>field polarization amplitude modulator</p>  <p>FUSE (36)</p>  <p>high-voltage primary cutout, dry</p>  <p>high-voltage primary cutout, oil</p>  <p>HYBRID (41)</p> <p>general</p>  <p>junction (common coaxial/waveguide usage)</p> 	<p>circular</p>  <p>(E, H or HE transverse field indicators replace (*) asterisk)</p> <p>INDUCTOR (42)</p> <p>general</p>  <p>magnetic core</p>  <p>tapped</p>  <p>adjustable, continuously adjustable</p>  <p>KEY, TELEGRAPH (43)</p>  <p>LAMP (44)</p> <p>ballast lamp; ballast tube</p>  <p>lamp, fluorescent, 2 and 4 terminal</p>  <p>lamp, glow; neon lamp a. c.</p>  <p>d. c.</p>  <p>lamp, incandescent</p>  <p>indicating lamp; switch-board lamp (see VISUAL SIGNALING DEVICE)</p>  <p>NUCLEAR-RADIATION DETECTOR, gas filled; IONIZATION CHAMBER; PROPORTIONAL COUNTER TUBE; GEIGER-MULLER COUNTER TUBE (50) (see RADIATION-SENSITIVITY INDICATOR)</p> 	<p>PICKUP HEAD (61)</p> <p>general</p>  <p>writing; recording</p>  <p>reading; playback</p>  <p>erasing</p>  <p>writing, reading, and erasing</p>  <p>stereo</p>  <p>RECTIFIER (65)</p> <p>semiconductor diode; metallic rectifier; electrolytic rectifier; asymmetrical varistor</p>  <p>mercury-pool tube power rectifier</p>  <p>RESISTOR (68)</p> <p>general</p>  <p>tapped</p>  <p>heating</p>  <p>symmetrical varistor resistor, voltage sensitive (silicon carbide, etc.)</p>  <p>(identification marks replace (*) asterisk)</p> <p>ROTARY JOINT, RF (COUPLER) (72)</p>  <p>general; with rectangular waveguide</p> 
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Figure 4-11.—Electronics symbols—Continued.

<p>(transmission path recognition symbol replaces (*) asterisk)</p> <p>coaxial type in rectangular waveguide</p> <p>circular waveguide type in rectangular waveguide</p> <p>SEMICONDUCTOR DEVICE (73) (Two Terminal, diode)</p> <p>semiconductor diode; rectifier</p> <p>capacitive diode (also Varicap, Varactor, resistance diode, parametric diode)</p> <p>breakdown diode, unidirectional (also backward diode, avalanche diode, voltage regulator diode, Zener diode, voltage reference diode)</p> <p>breakdown diode, bidirectional and backward diode (also bipolar voltage limiter)</p> <p>tunnel diode (also Esaki diode)</p> <p>temperature-dependent diode</p> <p>photodiode (also solar cell)</p>	<p>semiconductor diode, PNP switch (also Shockley diode, four-layer diode and SCR).</p> <p>(Multi-Terminal, transistor, etc.)</p> <p>PNP transistor</p> <p>NPN transistor</p> <p>unijunction transistor, N-type base</p> <p>unijunction transistor, P-type base</p> <p>field-effect transistor, N-type base</p> <p>field-effect transistor, P-type base</p> <p>semiconductor triode, PNP-type switch</p> <p>semiconductor triode, NPNP-type switch</p>	<p>NPN transistor, transverse-biased base</p> <p>PNIP transistor, ohmic connection to the intrinsic region</p> <p>NPIN transistor, ohmic connection to the intrinsic region</p> <p>PNIN transistor, ohmic connection to the intrinsic region</p> <p>NPIN transistor, ohmic connection to the intrinsic region</p> <p>SQUIB (75)</p> <p>explosive</p> <p>igniter</p> <p>sensing link; fusible link operated</p> <p>SWITCH (76)</p> <p>push button, circuit closing (make)</p> <p>push button, circuit opening (break)</p>	<p>nonlocking; momentary circuit closing (make)</p> <p>nonlocking; momentary circuit opening (break)</p> <p>transfer</p> <p>locking; circuit closing (make)</p> <p>locking; circuit opening (break)</p> <p>transfer, 3-position</p> <p>wafer</p> <p>(example shown: 3-pole 3-circuit with 2 non-shorting and 1 shorting moving contacts)</p> <p>safety interlock, circuit opening and closing</p> <p>SYNCHRO (78)</p> <p>Synchro Letter Combinations</p> <p>CDX Control-differential transmitter</p> <p>CT Control transformer</p> <p>CX Control transmitter</p> <p>TDR Torque-differential receiver</p> <p>TDX Torque-differential transmitter</p> <p>TR Torque receiver</p> <p>IX Torque transmitter</p> <p>RS Resolver</p> <p>B Outer winding rotatable in bearings</p>
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Figure 4-11.—Electronics symbols—Continued.

13.5.3

<p>THERMAL ELEMENT (83)</p> <p>actuating device</p> <p>OR</p> <p>thermal cutout; flasher</p> <p>OR</p> <p>thermal relay</p> <p>OR</p> <p>thermostat (operates on rising temperature), contact</p> <p>OR</p> <p>thermostat, make contact</p> <p>OR</p> <p>thermostat, integral heater and transfer contacts</p> <p>OR</p> <p>THERMISTOR; THERMAL RESISTOR (84)</p> <p>with integral heater</p>	<p>THERMOCOUPLE (85)</p> <p>temperature-measuring</p> <p>current-measuring, integral heater connected</p> <p>HEATER</p> <p>current-measuring, integral heater insulated</p> <p>HEATER</p> <p>temperature-measuring, semiconductor</p> <p>current-measuring, semiconductor</p> <p>TRANSFORMER (86)</p> <p>general</p> <p>OR</p> <p>magnetic-core</p>	<p>one winding with adjustable inductance</p> <p>separately adjustable inductance</p> <p>adjustable mutual inductor, constant-current</p> <p>autotransformer, 1-phase adjustable</p> <p>current, with polarity marking</p> <p>OR</p> <p>potential, with polarity mark</p> <p>OR</p> <p>VIBRATOR; INTERRUPTER (87)</p> <p>typical shunt drive (terminals shown)</p>	<p>typical separate drive (terminals shown)</p> <p>VISUAL SIGNALING DEVICE (88)</p> <p>communication switchboard-type lamp</p> <p>indicating, pilot, signaling, or switchboard light (see LAMP)</p> <p>OR</p> <p>OR</p> <p>(identification replaces (*) asterisk)</p> <p>indicating light letter combinations</p> <p>A Amber B Blue C Clear G Green NE Neon O Orange OP Opalescent P Purple R Red W White Y Yellow</p> <p>jeweled signal light</p>
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Figure 4-11.—Electronics symbols—Continued.

13.5.4

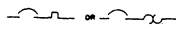
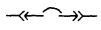
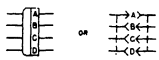

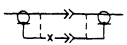



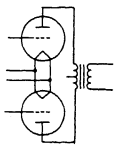



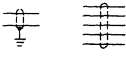

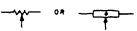
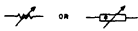






<p>CIRCUIT BREAKER (11) with magnetic overload</p>  <p>drawout type</p>  <p>CONNECTOR (18) engaged 4-conductor; the plug has 1 male and 3 female contacts, individual contact designations shown</p>  <p>coaxial, outside conductor shown carried through</p>  <p>coaxial, center conductor shown carried through; outside conductor not carried through</p>  <p>mated choke flanges in rectangular waveguide</p>  <p>COUPLER, DIRECTIONAL (27) (common coaxial/waveguide usage)</p> <p>E-plane aperture-coupling, 30-decibel transmission loss</p> 	<p>COUPLING (28) by loop from coaxial to circular waveguide, direct-current grounds connected</p>  <p>ELECTRON TUBE (34) typical wiring figure to show tube symbols placed in any convenient position</p>  <p>HYBRID (41) (common coaxial/waveguide usage)</p> <p>rectangular waveguide and coaxial coupling</p>  <p>MODE TRANSDUCER (53) (common coaxial/waveguide usage)</p> <p>transducer from rectangular waveguide to coaxial with mode suppression, direct-current grounds connected</p> 	<p>MOTION, MECHANICAL (54) rotation applied to a resistor</p>  <p>(identification replaces (*) asterisk)</p> <p>PATH, TRANSMISSION (58) cable; 2-conductor, shield grounded and 5-conductor shielded</p>  <p>RECTIFIER (65) fullwave bridge-type</p>  <p>RESISTOR (68) with adjustable contact</p>  <p>adjustable or continuously adjustable (variable)</p>  <p>(identification replaces (*) asterisk)</p> <p>RESONATOR, TUNED CAVITY (71) (common coaxial/waveguide usage)</p> <p>resonator with mode suppression coupled by an E-plane aperture to a guided transmission path and by a loop to a coaxial path</p> 	<p>tunable resonator with direct-current ground connected to an electron device and adjustably coupled by an E-plane aperture to a rectangular waveguide</p>  <p>SWITCH (76) 2-pole field-discharge knife, with terminals and discharge resistor</p>  <p>(identification replaces (*) asterisk)</p> <p>TRANSFORMER (86) with direct-current connections and mode suppression between two rectangular waveguides</p>  <p>(common coaxial/waveguide usage)</p> <p>shielded, with magnetic core</p>  <p>with a shield between windings, connected to the frame</p> 
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Figure 4-11.—Electronics symbols—Continued.

13.5.5

AMPLIFIER (2)	dipole	CIRCUIT ELEMENT (12)	DELAY LINE (31)
general 	loop 	general 	general
with two inputs 	counterpoise 	Circuit Element Letter Combinations (replaces (*) asterisk) EG Equalizer FAX Facsimile set FL Filter FL-BE Filter, band elimination FL-BP Filter, band pass FL-RP Filter, high pass FL-LP Filter, low pass PS Power supply RC Recording unit RU Reproducing unit DIAL Telephone dial TEL Telephone station TPR Teleprinter TTY Teletypewriter	tapped delay
with two outputs 	AUDIBLE SIGNALING DEVICE (6) bell, electrical; ringer, telephone 	Additional Letter Combinations (symbols preferred) AR Amplifier AT Attenuator C Capacitor CB Circuit breaker HS Handset I Indicating or switch board lamp L Inductor J Jack LS Loudspeaker MIC Microphone OSC Oscillator PAD Pad P Plug HT Receiver, headset K Relay R Resistor S Switch or key switch T Transformer WR Wall receptacle	bifilar slow-wave structure (commonly used in traveling-wave tubes)
with adjustable gain 	buzzer 		(length of delay indication replaces (*) asterisk) DISCONTINUITY (33) (common coaxial/waveguide usage) equivalent series element, general
with associated power supply 	horn, electrical; loudspeaker; siren; underwater sound hydrophone, projector or transducer 		capacitive reactance
with associated attenuator 	Horn, Letter Combinations (if required) *HN Horn, electrical *HW Howler *LS Loudspeaker *SN Siren †EM Electromagnetic with moving coil †EMN Electromagnetic with moving coil and neutralizing winding †MG Magnetic armature †PM Permanent magnet with moving coil	COUNTER, ELECTROMAGNETIC; MESSAGE REGISTER (26) general 	inductive reactance
with external feedback path 	identification replaces (*) asterisk and (†) dagger sounder, telegraph 	DETECTOR, PRIMARY; MEASURING TRANSDUCER (30) (see HALL GENERATOR and THERMAL CONVERTER) 	inductance-capacitance circuit, infinite reactance at resonance
Amplifier Letter Combinations (amplifier-use identification in symbol if required) BDG Bridging BST Booster CMP Compression DC Direct Current EXP Expansion LIM Limiting MON Monitoring PGM Program PRE Preliminary PWR Power TRQ Torque			inductance-capacitance circuit, zero reactance at resonance
ANTENNA (3)			resistance
general 			equivalent shunt element, general

Figure 4-11.—Electronics symbols—Continued.

<p>capacitive susceptance</p> <p>conductance</p> <p>inductive susceptance</p> <p>inductance-capacitance circuit, infinite susceptance at resonance</p> <p>inductance-capacitance circuit, zero susceptance at resonance</p> <p>GOVERNOR (Contact-making) (37)</p> <p>contacts shown here as closed</p> <p>HALL GENERATOR (39)</p> <p>HANDSET (40)</p> <p>general</p> <p>operator's set with push-to talk switch</p> <p>LOGIC (see 806B and Y32-14) (including some duplicate symbols; left- and right-hand symbols are not mixed)</p> <p>AND function</p> <p>OR function</p>	<p>EXCLUSIVE-OR function</p> <p>((*) input side of logic symbols in general)</p> <p>condition indicators</p> <p>state (logic negation)</p> <p>s Logic Negation output becomes 1-state if and only if the input is not 1-state</p> <p>an AND func. where output is low if and only if all inputs are high (NAND operation)</p> <p>electric inverter</p> <p>(elec. invtr. output becomes 1-state if and only if the input is not 1-state)</p> <p>(elec. invtr. output is more pos. if and only if input is less pos.)</p> <p>level (relative)</p> <p>1-state is less + 1-state is more +</p> <p>(symbol is a rt. triangle pointing in direction of flow)</p> <p>an AND func. with input 1-states at more pos. level and output 1-state at less pos. level (NAND operation)</p> <p>single shot (one output)</p> <p>(waveform data replaces inside/outside (*))</p> <p>Schmitt trigger, waveform and two outputs</p>	<p>flip-flop, complementary</p> <p>flip-flop, latch</p> <p>register</p> <p>(binary register denoting four flip-flops and bits)</p> <p>amplifier (see AMPLIFIER)</p> <p>channel path(s) (see PATH, TRANSMISSION)</p> <p>magnetic heads (see PICK-UP HEAD)</p> <p>oscillator (see OSCILLATOR)</p> <p>relay, contacts (see CONTACT, ELECTRICAL)</p> <p>relay, electromagnetic (see RELAY COIL RECOGNITION)</p> <p>signal flow (see DIRECTION OF FLOW)</p> <p>time delay (see DELAY LINE)</p> <p>time delay with typical delay taps:</p>	<p>functions not otherwise symbolized</p> <p>(identification replaces (*))</p> <p>Logic Letter Combinations</p> <p>S set</p> <p>C clear (reset)</p> <p>T toggle (trigger)</p> <p>(N) number of bits</p> <p>BO blocking oscillator</p> <p>CF cathode follower</p> <p>EF emitter follower</p> <p>FF flip-flop</p> <p>SS single shot</p> <p>ST schmitt trigger</p> <p>RG(N) register (N states)</p> <p>SR shift register</p> <p>MACHINE, ROTATING (46)</p> <p>generator</p> <p>motor</p> <p>METER, INSTRUMENT (48)</p> <p>identification replaces (*) asterisk)</p> <p>Meter Letter Combinations</p> <p>A Ammeter</p> <p>AH Ampere-hour</p> <p>CMA Contact-making (or breaking) ammeter</p> <p>CNC Contact-making (or breaking) clock</p> <p>CHV Contact-making (or breaking) voltmeter</p> <p>CRO Oscilloscope or cathode-ray oscillograph</p> <p>DB DB (decibel) meter</p> <p>DBM DBM (decibels referred to 1 milliwatt) meter</p> <p>DM Demand meter</p> <p>DTR Demand-totalizing relay</p> <p>F Frequency meter</p> <p>G Galvanometer</p> <p>GD Ground detector</p> <p>I Indicating</p> <p>INT Integrating</p> <p>μA or μA Microammeter</p> <p>MA Milliammeter</p> <p>NM Noise meter</p> <p>OHM Ohmmeter</p> <p>OP Oil pressure</p>
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Figure 4-11.—Electronics symbols.—Continued.

13.57

Armed with the knowledge of basic circuitry and symbols, most technicians, troubleshooting electronic circuits, will use a diagram of some form. The definitions of the different diagrams used are the same as those mentioned earlier; however, in most cases, they are somewhat more complicated. Figure 4-12 shows a typical diagram frequently used in the repair and installation of equipment using electronic circuitry. It is shown to give you some idea of what the diagrams look like.

SPECIFICATIONS

When project specifications are prepared, they must be brief, clear, and complete. Specifications must convey the complete description of the work to be performed in a clear, concise, and coherent manner, stating the actual minimum needs of the government and the conditions known, such as site location or special construction techniques. The use of general statements should be avoided.

The specifications should be used with construction drawings to provide the Utilitiesman the

needed details of the project. Basically, the drawings should show the extent, size, shape, generic types of material, and the relationship between different materials. The specifications should describe the quality of materials, the installation requirements, and the method of construction. The writer of the specifications should review the drawings while writing the specifications and after they have been completed. This ensures that the information appearing on the drawings has been covered in the specification and that all the requirements to accomplish the work have either been covered in detail on the drawings or described in the specifications. On the other hand, the designer or engineer should review the specifications to ensure complete coordination. Quite often, a simple detail, section, or note on the drawings makes it possible to eliminate lengthy, descriptive statements from the specification and at the same time clarify the designer's intent. Conflicts or duplications between drawings and specifications must be eliminated. The terminology used in specifications and drawings must be identical.

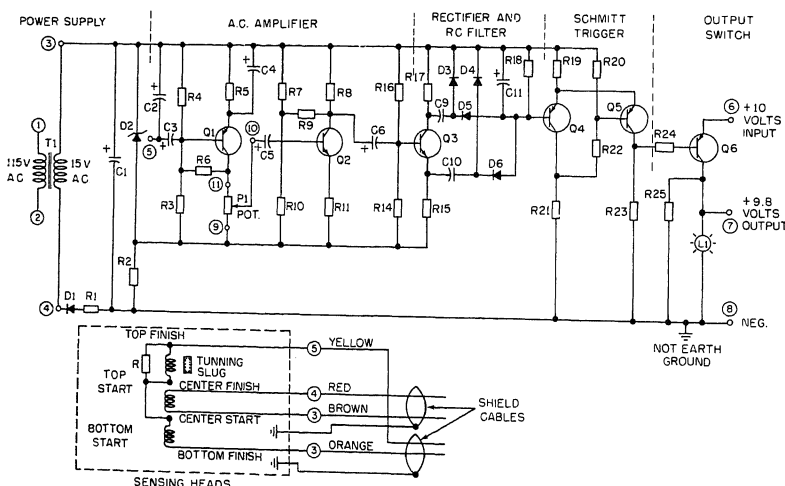


Figure 4-12.—Diagram of an electronic limit switch.

In short, the plans and the specifications are one and the same; when they are used as such, the desired results should be obtained.

AS-BUILT DRAWINGS

Upon the completion of a facility, the crew leader or project supervisor should provide operations with marked prints that indicate any construction deviations. The information required must show all features of the project as actually built. It is necessary that operations review the as-built drawings after they are completed. This assures that all information appearing on the drawings shows the exact as-built conditions.

From the as-built drawings, record drawings are prepared. These drawings are the original construction drawings, but are corrected according to the as-built marked print. They then provide a permanent record of as-built conditions. The original record drawings must be kept up-to-date at all times. If maintenance requires a change to the record drawing, this information should be passed back to operations or the maintenance control director (MCD) to update the record print.

SCHEDULES

The schedule is a systematic method of presenting notes and information in a tabular form. This makes the detailed information required easily accessible to the Utilitiesman and specifications writer. Schedules are used mostly on large projects.

A plumbing fixture schedule lists the fixture type and identifies each fixture type on the drawing by number. The manufacturer and catalog number of each type are given along with the number, size, and type of fixture. A column is left for additional remarks. This Remarks column may give such information as the mounting height above the finish floor (for wall mountings) or any other information required for proper installation.

Sometimes the same information can be found in the specifications of the project, but combing through page after page of written material can be time consuming. You may not always have access to the specifications while working, but the drawings are there. Therefore, the schedule is an excellent way of providing essential information in a clear and accurate manner, allowing you to carry out your task in the least amount of time.

CHAPTER REFERENCES

Blueprint Reading and Sketching, NAVEDTRA 10077-F, 1977, Naval Education and Training Program Development Center, Pensacola, Fla. 32509.

Construction Electrician 1 & C, NAVEDTRA 10637-E, 1985, Naval Education and Training Program Development Center, Pensacola, Fla. 32509.

Electrician's Mate 3 & 2, NAVEDTRA 10546-E1, 1981, Naval Education and Training Program Development Center, Pensacola, Fla. 32509.

CHAPTER 5

PLANNING, ESTIMATING, AND SCHEDULING

LEARNING OBJECTIVE: Identify the requirements needed for planning and estimating; identify the fundamentals and use of precedence diagrams for scheduling; recognize the computer management program used in the NCF.

Good construction planning and estimating procedures are essential to the Naval Construction Force's (NCF) ability to provide quality construction responsive to the fleet's operational requirements. This chapter contains information that can be used in planning, estimating, and scheduling construction projects normally undertaken by the SEABEES. This material is designed to be a helpful reference, NOT to establish procedures. The techniques described are suggested methods that have been proven with use and can result in effective planning and estimating. How and when these techniques are applied is left to the discretion of the user. The tables are included to be helpful references and are not intended to establish production standards. These tables must be used with sound judgment and modified as the user's experience suggests. Man-hour tables are based upon direct labor and do not include allowances for indirect or overhead labor.

In planning any project, you must have an idea of the meaning of the terms commonly associated with planning, estimating, and scheduling. We have defined 16 terms you will need in your job. Read them with care, but do not try to memorize them. Remember where you found them, so you can refer to these terms when you have to use them.

Planning is the process of determining requirements and devising and developing methods and a scheme of action for construction of a project. Good construction planning is a combination of various elements: the activity, material, equipment, and manpower estimates; project layout; material delivery and storage; work schedules; quality control; specialty tools required; environmental protection; safety; and progress control. All these elements depend upon

each other. All must be taken into account in any well-planned project.

Estimating is the process of determining the amount and type of work to be performed and the quantities of material, labor, and equipment required. The lists of these quantities and types of work are called estimates.

Preliminary Estimates are made from limited information, such as the general descriptions of projects or preliminary plans and specifications having little or no detail. Preliminary estimates are prepared to establish costs for the budget and to program general manpower requirements.

Detailed Estimates are precise statements of quantities of material, equipment, and manpower required to construct a given project. Underestimating quantities can cause serious delays in construction or can result in unfinished projects. A detailed estimate must be accurate to the smallest detail to correctly qualify requirements.

Activity Estimates consist of a listing of all the steps required to construct a given project, including specific descriptions as to the limits of each clearly definable quantity of work (activity). Activity quantities provide the basis for preparing the material, equipment, and manpower estimates. They are used to provide the basis for scheduling material deliveries, equipment, and manpower. Because activity estimates are used to prepare other estimates and schedules, errors in these estimates can be multiplied many times. Be careful in their preparation!

Material Estimates consist of a listing and description of the various materials and the quantities required to construct a given project. Information for preparing material estimates is obtained from the activity estimates, drawings, and specifications. A material estimate is

sometimes referred to as a bill of material (BM) or a material takeoff (MTO) sheet.

Equipment Estimates consist of a listing of the various types of equipment, the amount of time, and the number of pieces required to construct a given project. Information obtained from activity estimates, drawings, specifications, and an inspection of the site provide the basis for preparing the equipment estimates.

Manpower Estimates consist of a listing of the number of direct labor man-days required to complete the various activities of a specific project. These estimates may show only the man-days for each activity, or they may be in sufficient detail to list the number of man-days for each rating (Builder, Construction Electrician, Equipment Operator, Steelworker, and Utilitiesman) for each activity. Man-day estimates are used in determining the number of personnel and the ratings required on a deployment and in providing the basis for scheduling manpower in relation to construction progress.

A *Man-Day* is a unit of work performed by one person in one 8-hour day, or its equivalent, when NAVFAC P-405 is used and one 10-hour day, or its equivalent, when NAVFAC P-437 is used.

Direct Labor includes all the labor expended directly on assigned construction tasks either in the field or in the shop that contributes directly to the completion of the end product. Direct labor must be reported separately for each assigned construction item.

Overhead Labor is considered to be productive labor that does not contribute directly or indirectly to the product. It includes all labor that must be performed regardless of the assigned mission.

Indirect Labor includes the labor required to support construction operations but which does not produce an end product itself.

An *Estimator* is one who evaluates the requirements of a task. A construction estimator must be able to mentally picture the separate operations of the job as the work progresses through the various stages of construction and be able to read and obtain accurate measurements from drawings. The estimator must possess a knowledge of mathematics, have previous construction experience, and have a working knowledge of all branches of construction. The estimator must use good judgment when determining what effect numerous factors and conditions will have on construction of the project and

what allowances should be made for each of them. The estimator must be able to do careful and accurate work. A SEABEE estimator must have ready access to information about the material, the equipment, and the labor required to perform various types of work under conditions encountered in SEABEE deployments. The collection of such information on construction performance is a part of the job of estimating. This kind of reference information may change from time to time; therefore, this data should be reviewed frequently.

Scheduling is the process of determining when an action must be taken and when material, equipment, and manpower will be required. *PROGRESS SCHEDULES* coordinate all the projects of a SEABEE deployment or all the activities of a single project. They show the sequence, the starting time, the performance time required, and the time required for completion. *MATERIAL SCHEDULES* show when the material is needed on the job and may show the order in which materials should be delivered. *EQUIPMENT SCHEDULES* coordinate all the equipment to be used on a project, show when it is to be used, and show the amount of time each piece of equipment is required to perform the work. *MANPOWER SCHEDULES* coordinate the manpower requirements of a project and show the number of personnel required for each activity. In addition, the number of each rating (Builder, Construction Electrician, Equipment Operator, Steelworker, and Utilitiesman) required for each activity for each period of time may also be shown. The selected unit of time to be shown in a schedule should be some convenient interval, such as a day, a week, or a month.

Network Analysis is a method of planning and controlling projects by recording their interdependence in a diagram form. This enables each fundamental problem involved to be undertaken separately. The diagram form, known as a network diagram, is drawn so each job is represented by an activity on the diagram, as shown in figure 5-1. The direction in which the activities are linked indicates the dependencies of the jobs on each other.

Progress Control is the comparing of actual progress with scheduled progress and the steps necessary to correct deficiencies or to balance activities to meet the overall objectives.

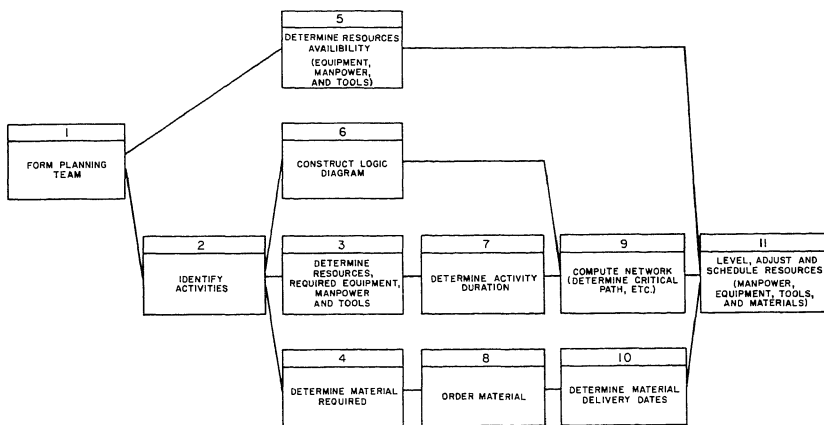


Figure 5-1.—Planning and estimating precedence diagram.

26.317

PLANNING

The basic ground rules in analyzing a project are that planning and scheduling are separate operations and that planning must always precede scheduling. When these two steps are done at the same time, they generally introduce elements of scheduling prematurely, thus clouding the picture of the plan and severely limiting its flexibility.

Everyone concerned should know precisely what the project is, its start and finish points, its external factors, such as the schedule dates and requirements of other trade groups, and the availability of resources, such as manpower and equipment.

All projects consist of separate, but interrelated, operations. In network analysis, these operations are called activities. The first stage in applying this technique is to develop an activity list that describes the project to be scheduled. You can obtain this list in various ways: by studying the manufacturers' specifications, the bills of material, the technical drawings, the modification(s) of a previous application, and the work sheets for a previous project. Also, a joint discussion should be held by those persons who sufficiently understand the project. Use the last method even if a tentative list has been obtained by other means.

There are no specific definitions as to what makes up an activity; it is largely a matter for individual interpretation according to the requirements of a particular project. A useful guideline is to ask the following three questions about any particular activity in the network.

1. Would the activity normally be regarded as continuous from start to finish? This does not mean it may not prove expedient to split the activity later to help scheduling. The key here is the word normally.
2. Will the required resources remain constant throughout the duration of the activity? Sometimes constant resources may not be achievable, even though they make control easier.
3. Is the amount of work involved small enough to allow a reliable duration estimate to be assigned to the activity?

No attempt should be made to minimize the number of activities in a network by leaving out those considered to be unimportant and that have considerable float. They can easily be forgotten. Their omission could lead to an entirely false analysis.

One further point to remember: there may be space limitations in the computer (discussed later in this chapter) for activity descriptions. Each activity should be given a fairly concise title that will identify it in the computer printout.

ESTIMATING TECHNIQUES

For you, as the estimator, to prepare a detailed and accurate estimate, information must be available about various conditions affecting construction of the project. The drawings should be detailed and complete. The specifications should be exact. They should leave no doubt as to their intent. Information should be available about local material, such as quarries, gravel pits, spoil areas, types of soil, haul roads and distances, foundation conditions, the weather expected during construction, and the time allotted for completion. Know the number and types of construction equipment available for use. Consider all other items and conditions that might affect production or the progress of construction.

NEED FOR ACCURACY IN THE USE OF DRAWINGS AND SPECIFICATIONS

Information found on drawings is the main basis for defining the required activities and for measuring the quantities of material. Accurate estimating requires a thorough examination of the drawings. Read all notes and references carefully. Examine all detail and reference drawings. In preference to scaling, use the dimensions shown on the drawings or figures. If you need to scale dimensions, use a scale rule; also check for expansion or shrinkage of the graphic scale on the drawings. When there is disagreement between the plans, elevations, and details, you normally follow the detail drawing. When there is disagreement between the specifications and the drawings, you normally follow the specifications.

When preparing the activity, equipment, and quantity estimates, use the specifications with the drawings. Be familiar with all the requirements contained therein, such as unfamiliar work procedures or material, and the specific requirements in testing various mechanical systems. You may have to read the specifications several times to fix these requirements in mind. Notes made while reading the specifications will help you when the drawings are being examined and when realistic estimates are being made. When checking the

estimates, it helps to have a list of the activities and the material described. Specifications often contain information required for preparing purchase requisitions; note this data for use later in preparing material lists. Wrong interpretation of a section of the specifications can cause errors in the estimate. If there is any doubt about the meaning of any portion of the specifications, request an explanation.

The tables and diagrams in NAVFAC P-405, *SEABEE Planner's and Estimator's Handbook*, will save you time in preparing estimates and, when understood and used properly, will give accurate results. Wherever possible, the tables and the diagrams used are based on the SEABEES' experience. Where suitable information was not available, construction industry experience was adjusted to represent production under the range of conditions encountered in SEABEE construction.

A thorough knowledge of the project drawings and specifications will make you alert to the various areas where errors may occur. The most common sources of errors in quantity estimates are as follows:

1. Failure to read all the notes and references on the drawing
2. Errors in scaling drawings that result in erroneous quantities
3. Omissions caused by careless examination of the drawing
4. Failure to make proper allowances for material loss/waste caused by cutting and handling

Make a thorough examination of the drawings and a proper allowance of the material. This action will greatly improve the accuracy of the quantity estimate. As the estimator, check changes or updates to the drawings and changes in material quantities added to the material estimate.

ACTIVITY ESTIMATES

The activity estimate provides a basis for preparing the estimate of material, the equipment, and the manpower requirements. An activity estimate, for example, might call for rough-in piping in a floor slab. In the activity estimate, your immediate concern is to identify the material necessary to do the task; that is, pipe, fittings, joining materials, and so forth. The equipment estimate for this activity would consider vehicles for movement of material and special tools; that is, portable power tools, a threader, a power vise, and so forth. From the scope of the activity and

the time restraints, you can estimate the manpower required. The information shown in the activity estimate is also useful in scheduling progress and in providing the basis for scheduling deliveries of material, equipment, and manpower to the jobsite.

The following techniques have been proven through use, and you will find they produce satisfactory results in obtaining activity estimates. Become knowledgeable of the project by studying the drawings, reading the specifications, and examining all available information concerning the site and local conditions. Only after first becoming familiar with the project are you ready to identify individual activities. First, define activities as they may vary depending on the scope of the project. An activity is a clearly definable quantity of work. For estimating and scheduling, an activity for a single building or job should be a specific task or work element done by a single trade. For scheduling of large-scale projects, a complete building may be defined as an activity; but for estimating, it must remain at the single-task, single-trade level. After becoming familiar with the project and defining its scope, proceed

with identifying the individual activities required to construct the project. To identify activities, be sure each activity description shows a specific quantity of work with clear, definite limitations or cutoff points that can be readily understood by everyone concerned with the project. Prepare a list of these activities in a logical sequence to check for completeness.

Material Estimate

Material estimates are used to procure construction material and to determine if sufficient material is available to construct or complete a project. The sample forms shown in figures 5-2, 5-3, and 5-4 may be used in preparing material estimates. The forms are presented as one method of recording the various steps taken in preparing a material estimate. Each step can readily be understood when the work sheets are reviewed. A work sheet must have a heading that shows the project title, project location, drawing number, sheet number, project section, prepared by, checked by, and the date. The estimating work sheet (fig. 5-2), when completed, will show the

ESTIMATING WORK SHEET									
PREPARED BY: E.B. JASON		PROJ. LOCATION: DIEGO GARCIA		SHEET 1 OF 5		DRAWING NO. 1,337,494/7,604/98		PROJ. TITLE: CANTONMENT AREA	
CHECKED BY: T.J. ABERNATHY		PROJ. SECTION: ARCHITECTURAL		ACTIVITY NO. NO. 21 TO NO. 69		BM NO. D1W-112		DATE PREPARED: 19 FEB '85	
ITEM NO.	DESCRIPTION	PREFAB FORMS	REFER TO DWG. Q.D. SECT. V PAR B+C PP 7-8	BM NO.	BM LINE ITEM NO.	UNIT OF ISSUE	TOTAL QTY	REMARKS	
	BUILDING FOOTING	L W T							USE LOG. PROCEDURES ETC
		26'-0" 20'-0" 12"							SLAB/FOOTING
1.	3/4" PLYWOOD BB EXTERIOR TYPE 4'x8'	2 (26'-0" + 20')/2 = 53'-0" + 40' = 93'-0"			1	SH	0	3	EDGE FORMS-TO BE USED AT TRANSMITTER SITE BLDG.
		93.33/32' = 3 SHEETS							
2.	LUMBER 1x6xRL GR 2 OR BETTER	6' LENGTH x 2 EA. CORNER x 4 CORNERS = 8 PCS / 6 LONG			2	BF	15	30	BLDG LAYOUT BATTER BOARDS
3.	LUMBER 2x4xRL	16' - 48 PCS - 16'x2x4x48 PCS			3	BF	15	590	USE REUSABLE 2x4 AT TRANSMITTER SITE BUILDING
	RAMP AND DOOR STOOP FORMS								
4.	3/4" PLYWOOD 4'x8'	(13'-8" + 2 (6') + 3 (4')) = 37'-0" RP PLYWOOD INTO 8" STRIPS = 6 X 8 = 48			1	SH	0	1	EDGE FORMS REUSE AT TRANSMITTER SITE BUILDING
	BEAMS								
	B-1	2 EACH 24'-8" BOND BEAMS							
5.	3/4" PLYWOOD GR BB EXT TYPE 4'x8'	26'-8" x 4 SIDES = 106'-8"			1	SH	0	10	B-1 SIDE FORMS REUSE AT TRANSMITTER SITE BUILDING

Figure 5-2.—Typical estimating work sheet.

various individual activities for a project with a listing of the required material. Material scheduled for several activities or uses will be shown in the Remarks section. The work sheet should also contain an activity description, the item number, a material description, the cost, the unit of issue, the waste factors, the total quantities, and the remarks. The estimating work sheets should be kept by the field supervisor during construction to ensure use of the material as planned. The material takeoff (MTO) sheet (fig. 5-3) shows, in addition to the information listed above, the suggested vendor(s) or source(s), supply status, national stock number (NSN), and the required delivery date. The bill of material (BM) sheet (fig. 5-4) is similar in content to the material takeoff sheet; the information is presented in a format suitable for data processing. For requests of supply status, issue, or location of material, use this form. Use the bill of material sheets for preparing purchase documents. When funding data have been added, use these sheets for drawing against existing supply stocks.

Use checklists to eliminate any omissions from the material estimates. Prepare a list for each individual project when you examine the drawings, specifications, and activity estimates. This is the practical way to prepare a listing of the variety of the material used in a project. The listing will apply only to the project for which it has been prepared. If no mistakes or omissions have been made in either the checklist or estimate, the

Figure 5-3.—Typical material takeoff sheet.

The procedure for preparing a material estimate is to determine the activity by using the activity description with the detailed information given in or on the drawings and plans to provide a quantity of work. This quantity is then converted to the material required. Next, enter the conversion on a work sheet to show how each quantity was obtained, as shown in figure 5-2. Work sheets need to be sufficiently detailed to be self-explanatory, so anyone examining them can determine how the quantities were computed.

Equipment Estimate

Equipment estimates are used with production schedules to determine the construction equipment requirements and constraints for SEABEE deployment. Of these constraints, the movement of material over roadways is frequently miscalculated. In the past, estimators used the posted speed limits as an average rate for moving material; this concept was wrong. Equipment speed will usually average between 40 to 56 percent of the posted speed limit. Factors, such as the road conditions, the number of intersections, the amount of traffic, and the hauling distances

BILL OF MATERIAL DS-205 (REV. 1-67) (7-7)				PROJECT INTERIM WATER SYSTEM REINDER STATION (CANTONMENT AREA)										SHIP APRIL '85		-- L.V. 112		
SUBMITTER GORDON																		
ABOUT TODAY	DATE RECD	KEYS & SUPP ADDRESS	FUNDING CONTRACT NO.	PROJECT NO.	PRI	MOD	JOB ORDER	NEW ITEM DATE										
P962	N62583	N YW112	A TMMZM905	094			4K6404											
DOC IDENT	SEC	STOCK NUMBER NITW	QTY REQD	QUANTITY	DOCUMENT NUMBER	DATE ACFTAL	CAN	ADJ	UNIT LBS	DESCRIPTION / SPEC / CMT OR VENDORS	UNIT COST	TOTAL COST	STD/DATA REC'D	STD/DATA ISSUED				
AFE		SH	69	40817005	1					PLYWOOD, 3/4" X 4' X 8' BB EXTERIOR TYPE SUGGESTED VENDOR: THOMPSON LUMBER CO.	12.00	820.00						
		BF	30	7904	2					LUMBER, SOFTWOOD, 1"x6" x 12' STANDARD CONSTRUCTION GRADE 2 OR BETTER, SUGGESTED VENDOR: THOMPSON LUMBER CO.	.18	5.40						
		BF	224E	7907	3					LUMBER, SOFTWOOD, 2"x6" x 16' STANDARD CONSTRUCTION GRADE 2 OR BETTER, SUGGESTED VENDOR: THOMPSON LUMBER CO.	.28	627.76						
		BF	144	7906	4					LUMBER, SOFTWOOD, 2"x6" x 16' STANDARD CONSTRUCTION GRADE 2 OR BETTER, SUGGESTED VENDOR: THOMPSON LUMBER CO.	.28	40.32						
TOTAL																		
\$ 1701.48																		

Figure 5-4.—Sample bill of material sheet.

will vary the percentage of the posted speed limit. The percentage may be used with a degree of accuracy. Other factors used are types of material hauled (for example, damp sand or loam is much easier to handle than clay), safety (machine limitations), operators' experience, condition of the equipment, work hours, and the local climate.

Equipment production must be determined so the amount and type of equipment may be

selected. Equipment production rates are available in the *SEABEE Planner's and Estimator's Handbook*, NAVFAC P-405. The tables provide information as to the type of equipment required. The production rate per day should be estimated for each piece of equipment. Consider the factors discussed above, information obtained from NAVFAC P-405, and your experience. The quantity of work divided by the production rate per day will produce the number of days required

SHEET <u>1</u> OF <u>2</u>		
ESTIMATED BY <u>Brown</u>		DATE <u>6/15/85</u>
CHECKED BY <u>Green</u>		DATE <u>6/23/85</u>
EQUIPMENT ESTIMATE		
NMCB _____	LOCATION <u>GUAM</u>	YEAR <u>1985</u>
PROJECT <u>No. 013</u>	DESCRIPTION <u>Site Preparation</u>	
<p>Earth Fill — 36,000 CY loose measurement required. Haul one way 2-1/2 miles. Use 2-1/2 CY endloader and 10 CY dump trucks.</p> <p>Endloader capacity 100 CY/hours.</p> <p>$\frac{36,000}{100} = 360$ hours or 45 eight-hour days.</p> <p>$\frac{100}{10} = 10$ trucks loaded per hour.</p> <p>Average hauling speed estimated at 15 MPH.</p> <p>$2 \times 2.5 = 5$ miles round trip.</p> <p>$5/15 \times 60 = 20$ minutes hauling time.</p> <p>$60/10 = 6$ minutes loading time.</p> <p>Estimated 4 minutes dumping time.</p> <p>30 minutes total time per truckload.</p> <p>$60/30 = 2$ loads per hour per truck.</p> <p>$10/2 = 5$ trucks required to keep endloader working at capacity.</p> <p>$100 \times 8 = 800$ CY hauled per 8-hour day.</p> <p>Need one bulldozer (can spread 1400 CY daily).</p> <p>Need one grader to keep haul road in shape.</p> <p>1 bulldozer (can spread 1400 CY daily).</p> <p>1 tractor & tandem sheepfoot roller (can compact 1200 CY daily).</p> <p>1 water truck with sprinkler for moisture control.</p> <p>1 rubber-tired wobbly wheel roller on standby for compaction and sealing fill when rain is expected. (Can be towed by above bulldozer or tractor).</p>		

Figure 5-5.—Sample equipment estimate (sheet 1 of 2).

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to perform the project. After you determine the number of days of required equipment operation, consult the project schedule to find the time allotted to complete the activities. Prepare the schedule for the total deployment; use the project schedule to determine when the work will be performed. The schedule will also indicate peak usage; it may have to be revised for more even distribution of equipment loading, thereby reducing the amount of equipment required during the deployment.

After the reviews and revisions, prepare a list of equipment required. The list must include

anticipated downtime. Sufficient reserve pieces must be added to cover any downtime.

To aid in the preparation of the equipment estimate schedule, use forms, such as those shown in figures 5-5 and 5-6. The important information on the forms includes the sheet number, estimator's name, checker's name, date checked, battalion and detachment number, location of deployment, year of deployment, project number, and a brief description of the project.

The naval mobile construction battalion's (NMCB) table of allowance (TOA) contains

SHEET <u>2</u> OF <u>2</u>			
ESTIMATED BY <u>Brown</u>		DATE <u>6/13/85</u>	
CHECKED BY <u>Green</u>		DATE <u>6/23/85</u>	
EQUIPMENT ESTIMATE			
NMCB <u> </u>	LOCATION <u>GUAM</u>	YEAR <u>1985</u>	
PROJECT <u>No. 013</u>	DESCRIPTION <u>Site Preparation</u>		
<p>NOTE: Spreading is not very efficient, as spreading equipment is not used to full capacity. Suppose that when the work schedule is prepared, completion of fill will be required in 18 days. Assume that climate is such that 3 days in every 17 working days will be lost due to rain. Therefore, 15 working days would be available in an 18 day schedule.</p> <p>$3,600/15 = 2,400$ cu. yd. must be hauled daily to complete the work on schedule.</p> <p>$2,400/800 = 3$ times the output of loading and hauling spread shown previously.</p> <p>Equipment required for loading and hauling:</p> <ul style="list-style-type: none"> 3 — 2-1/2 cu.yd. endloaders. 1 — bulldozer to keep pit in shape. 1 — grader to keep haul road in shape. 15 — 10-ton trucks hauling (1 or 2 extra trucks should be added to assure that a truck will always be waiting to be loaded so that endloader will work at full capacity). <p>$2,400$ cu. yd. will be hauled each day.</p> <p>$2,400/1,200 = 2$ tractors and tandem sheepfoot roller for compaction. 2 bulldozers to spread earth.</p> <p>$2,400/1,400 = 1$ water truck with sprinkler.</p> <p>1 wobbly-wheel roller (standby for sealing of fill before rains).</p> <p>NOTE: This is a more efficient operation, as production has been tripled but equipment has not, and total equipment working at or as close to capacity as can be expected.</p>			

Figure 5-6.—Sample equipment estimate (sheet 2 of 2).

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specific information on the quantities and characteristics of construction equipment available to the NMCBs. Table 5-1 contains an abbreviated listing of such equipment.

Labor Estimate

There are two types of labor estimates—preliminary manpower estimates and detailed manpower estimates. Use preliminary manpower

estimates to establish costs for the budget and to project manpower requirements for succeeding projects and deployments. The estimates are prepared from limited information, such as general descriptions or preliminary plans and specifications that contain little or no detailed information; for example, area, length, or other suitable measurement. In some cases, you can make a comparison with similar facilities of the same basic design, size, and type of construction. A good preliminary estimate varies less than

Table 5-1.—NMCB Construction Equipment Characteristics

QUANTITY	EQUIPMENT DESCRIPTION
12 8	TRUCKS Dump, 6 x 6, 5 Ton, 5 Cu. Yd. Capacity Dump, 6 x 4, 15 Ton, 10 Cu. Yd. Capacity
6	GRADERS Motor, Road, 12 Ft. Blade, 6 x 4, with Scarifier
4 2 2	LOADERS Scoop, Full Tracked, 2 ½ Cu. Yd. Multipurpose Bucket Scoop, Wheeled, 4 x 4, 2 ½ Cu. Yd. Std. Bucket with Forks Scoop, Wheeled, 4 x 4, 2 ½ Cu. Yd. Std. Bucket with Forks Backhoe, Crane, Dozer Blade
2 3	ROLLERS Oscillating, Self-Propelled, 9 Wheel, Pneumatic Tired Vibrating, Self-Propelled, Pneumatic Tired, Single Drum
6	SCRAPERS Tractor, Whl, 14 to 20 Cu. Yd., Hydraulic
5 2 1	TRACTORS Crawler, Hydraulic Semi-U Tilt Dozer Crawler, Hydraulic Angle Dozer, Winch Crawler, Hydraulic Semi-U-Dozer, Hydraulic Ripper
2 1 1	CRANES Truck, Mounted, 8 x 4, 35 Ton, 60 Ft. Boom with Extension Truck, Mounted, 8 x 4, 25 Ton, Hydraulic Tractor, Wheel Mounted, 4 x 4, 12 ½ Ton, Telescoping Boom, Hydraulic
1 2 2 2 2 2 2 8	SPECIALIZED EQUIPMENT Distributor, Bituminous Material, Truck Mounted, 6 x 4, 2,000 Gal Capacity Distributor, Water, Truck Mounted, 6 x 6 2,000 Gal. Capacity Distributor, Water, Wagon Mounted, 8,000 Gal. Capacity Ditching Machine, Ladder Type, 8 to 24 In. Width by 7 Ft. Depth, Crawler Mounted Excavator, Multi-Purpose, Hydraulic, 6 x 6, 11 Ft. 1 In. Digging Depth, Truck Mounted Auger, Earth, Truck Mounted Truck, Forklift, Rough Terrain, 6,000 Lb. Capacity, Pneumatic Tired

15 percent from the detailed estimate. Use detailed manpower estimates to determine the manpower requirements for construction of a given project and the total direct labor requirements of a deployment. Use the individual activity quantities taken from the activity work sheet to prepare detailed estimates. Then, select the man-hours per unit figure from the appropriate table in NAVFAC P-405 and multiply it by the quantity to obtain the total man-hours required. When you prepare the activity estimates in the format discussed earlier, you may use a copy of the activity estimates as a manpower estimate work sheet by adding three columns to it with the headings of Activity Quantity, Man-Hours Per Unit, and Total Man-Days Required. Work sheets, whether on the activity work sheet or on another format, should be prepared in sufficient detail to provide the degree of progress control desired; for example, the work sheets should show the following information. (NOTE: 8 man-hours equal 1 man-day.)

Description	Quantity	Man-Hours Per Unit	Total Man-Days
Install 12-inch diameter concrete pipe	2,500 feet	20/100	62.5
Install 30-inch diameter concrete pipe	2,500 feet	80/100	250.0
	5,000 feet		312.5

If the control is to be exercised only on concrete pipe installation without regard to detail, the manpower estimate would show the following information on the summary sheet.

Description	Quantity	Man-Hours Per Unit	Total Man-Days
Install concrete pipe	5,000 feet	50/100	312.5

The man-hours per unit on the work sheet is obtained by dividing the total man-days shown in the detail estimate by the total feet of concrete pipe times the unit to obtain the average man-hours. The man-hours per unit will be used for checking actual progress.

Check manpower estimates against the activity estimate to assure that no activities have been omitted.

Tables 4-110 through 4-125 of NAVFAC P-405 provide labor estimates for the various projects undertaken by the UTs.

Facilities Planning Guide, NAVFAC P-437, Volumes 1 and 2, is an excellent source for preliminary estimates. It can be used to find estimates for a wide range of facilities and assemblies commonly constructed. The P-437 not only gives the man-hours required, but it also gives a breakdown of the construction effort by ratings (BU, CE, UT, and so forth), as well as lapsed day estimates.

You must bear in mind that the lapse time from the P-437 is calculated using the contingency norm of a 10-hour man-day instead of the 8-hour man-day used in the P-405. For example, a specific task from the P-437 requires 100 man-hours of UT effort. The optimum crew is four UTs. This will yield the following lapse time:

$$\frac{100 \text{ MH}}{4 \text{ UTs} \times 10 \text{ hours}} = 2.5 \text{ days (lapse time)}$$

For this same task using the P-405, an 8-hour man-day would yield the following:

$$\frac{100 \text{ MH}}{4 \text{ UTs} \times 8 \text{ hours}} = 3.1 \text{ days (lapse time)}$$

In preparing manpower estimates, weigh the various factors that affect the amount of labor required to construct a project. These factors are weather conditions during the construction period, the skill and experience of the personnel who will perform the work, the time allotted for completion of the job, the size of the crew to be used, the accessibility of the site, and the types of material and equipment to be used.

The production efficiency guide chart, table 5-2, lists eight elements that directly affect production. Each production element is matched with three areas for evaluation. Each element contains two or more foreseen conditions from which to select for the job in question. Evaluate each production element at some percentage between 25 and 100, according to your analysis of the foreseen conditions. The average of the eight evaluations is the overall production efficiency percentage. Then convert the percentage to a delay factor on the production efficiency graph

Table 5-2.—Production Efficiency Guide Chart

		LOW PRODUCTION			AVERAGE PRODUCTION			HIGH PRODUCTION			
		PRODUCTION ELEMENTS (PERCENT)									
		25	35	45	55	65	75	85	90	95	100
		FORESEEN CONDITIONS									
1.	Workload	Const. requirement high; misc. overhead high			Const. requirement normal; misc. overhead normal.			Const. requirement low; misc. overhead low.			
2.	Site Area	Cramped working area, no area for material storage; work restricted to design; poor job layout			Work area limited slightly; partial material storage; some variation from design; average job layout.			Large work area; adequate material storage; wide latitude from design; good job layout.			
3.	Labor	Poorly trained; low strength; low morale; high sick call.			Average trained; normal strength; fair morale; normal sick call.			Highly trained; over strength; high morale; low sick call.			
4.	Supervision	Poor management; poorly trained personnel; low strength			Average management; average trained personnel; normal strength.			Efficient management; highly trained personnel; over strength.			
5.	Job Conditions	High quality work required; unfavorable site materials; short time operations; insect annoyance high			Average work required; average site materials; reasonable operation time; insect annoyance normal.			Passable work required; good site materials; long time operation; no insect annoyance.			
6.	Weather	Abnormal rain; abnormal heat; abnormal cold.			Moderate rain; moderate heat; moderate cold.			Some rain; occasional heat; occasional cold.			
7.	Equipment	Improper job application; equipment in poor condition; repair and maintenance inadequate			Fair job application; equipment in average condition; repair and maintenance average.			Efficient job application; equipment in good condition; efficient repair and maintenance.			
8.	Tactical and Logistical	Slow supply delivery; frequent tactical delays			Normal supply delivery; occasional tactical delays.			Prompt supply delivery; no tactical delays.			

NOTES:

- The weights of the elements can be adjusted if known facts so indicate.
- Rainfall is normally treated separately in the area of calendar day scheduling. Predictions of lost construction days are based on geographic rainfall charts. Typhoon and hurricane seasons can cause considerable lost time in securing jobsites for alerts and warnings even if work areas are not directly in the path of the storm.
- The tactical delay area of consideration should include: Night travel restrictions, mine sweeps on roads into the work area, preparation of zig-zag trenches or individual protective measure, sabotage of equipment or materials left on the jobsite, and any additional security requirements that detract from the assigned work force.
- The continual pilferage and theft of tools and materials can affect production and is very common in some areas of the world. This condition requires abnormal controls and security, which in turn slows production.

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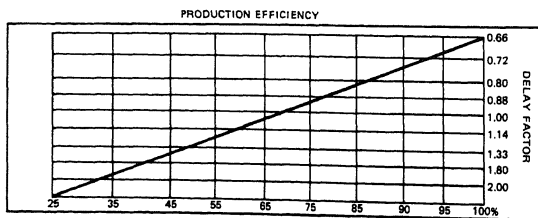


Figure 5-7.—Production efficiency graph.

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(fig. 5-7). It is strongly recommended that the field or project supervisors reevaluate the various production elements and make the necessary adjustments to man-day figures based on the actual conditions at the jobsite.

NOTE: The estimate of average SEABEE production used in the NAVFAC P-405 tables falls at 67 percent on the bottom of the graph shown in figure 5-7, which in turn will be a delay factor of 1.00 on the right. A delay of 0.66 represents peak production.

In reading the graph, note that the production element at the bottom of the graph is computed; an imaginary vertical line is drawn from that point to dissect the diagonal line; then the delay factor may be read from the right vertical Delay Factor line. As an example, assume that from the work estimate taken from the tables in P-405, you find that 6 man-hours are needed for a given unit of work. To adjust this figure to the conditions evaluated on your job, assume that the average of foreseen conditions rated by you is 87 percent. The corresponding delay factor read off the production efficiency graph is 0.80. You find the adjusted man-hour estimate by multiplying this delay factor by the man-hours from the estimating tables ($6 \text{ MH} \times 0.8 = 4.8 = \text{the adjusted man-hour estimate}$).

The man-hour labor estimating tables are arranged and grouped together into the 16 major divisions of work. This is the same system used in the preparation of government construction specifications. The 16 major divisions of work are as follows:

1. General
2. Site Work
3. Concrete
4. Masonry
5. Metal
6. Carpentry
7. Moisture Protection
8. Doors, Windows, Glass
9. Finishes
10. Specialties
11. Architectural Equipment
12. Furnishings
13. Special Construction
14. Conveying Systems
15. Mechanical
16. Electrical

The activities in the various labor estimating tables are divided into units of measurement

commonly associated with each craft and material takeoff quantities. There is only one amount of man-hour effort per unit of work. This number represents normal SEABEE production under average conditions. As used herein, 1 man-day equals 8 man-hours of direct labor. Man-day figures do not include overhead items, such as dental or personnel visits, transportation to and from the jobsite, or inclement weather.

No two jobs will be exactly alike nor will they have exactly the same conditions. Therefore, you, as the estimator, must exercise some judgment about the project that is being planned. The production efficiency guide and graph (table 5-2 and fig. 5-7) are provided to assist you in weighing the many factors that contribute to varying production conditions and the eventual completion of a project. You can then translate what is known about a particular project, producing a more accurate quantity from the average figures given on the labor estimating tables.

SCHEDULING BY NETWORK ANALYSIS TECHNIQUES

After World War II, the construction industry experienced the same critical examination the manufacturing industry had experienced 50 years before. Large construction projects came under the same pressures of time, resources, and cost that had prompted studies in scientific management in the factories about 1900.

The emphasis, however, was not on actual building methods, but upon the management techniques of programming and scheduling. The only planning methods used were those that had been developed for use in factories. Management tried to use these methods for the control of large construction projects. These techniques suffered from serious limitations in project work. The need to overcome these limitations led to the development of the network analysis techniques.

In the late 1950s, this new system of project planning, scheduling, and control came into widespread use in the construction industry. Critical path analysis (CPA), critical path method (CPM), and project evaluation and review technique (PERT) represent about 50 titles approaches. The basis of any of these approaches is the analysis of a network of events and activities. For this reason, the generic title covering the various networks is *Network Analysis*.

These network analysis techniques are now the accepted method of construction planning in

many organizations. They form the core of project planning and control systems.

ADVANTAGES OF NETWORK ANALYSIS

There are many advantages of network analysis. As a management tool, it readily separates the planning from the scheduling of time. The diagram, a picture representation of the project, enables you to see the interdependencies between events and the overall project to prevent unrealistic or superficial planning. Resources and time restraints are easily detachable to allow adjustments to be included in the plan before its evaluation.

Because the system splits the project into individual events, estimates and lead times are more accurate. Deviations from the schedule are quickly noticed. Manpower, material, and equipment resources are easily identifiable. Since the network remains constant throughout its duration, it is also a statement of logic and policy. Modifications of the policy are allowed, and the impact on events is assessed quickly.

Identification of the critical path is useful if the completion date has to be advanced. Attention can then be concentrated toward speeding up those relatively few critical events. The network allows you to analyze critical events accurately and to effectively provide the basis for the preparation of charts which results in better control of the entire project.

DISADVANTAGES OF NETWORK ANALYSIS

The only disadvantage of network analysis as a planning tool is that it is a tedious and an exacting task when attempted manually. Depending upon just what the project manager wants as output, the number of activities that can be handled without a computer varies, but the number is never very high.

Calculations are in terms of the sequence of activities; and, if this is all, a project involving several hundred activities may be attempted manually. However, the chance for error is high. Suppose the jobs are to be sorted by rating, so that jobs undertaken by Utilitiesmen are together as are those for Equipment Operators or construction Electricians. The time required for manual operation would become costly. The consideration of various alternative plans also becomes impossible because of the large volumes.

On the other hand, standard computer programs for network analysis can handle project

plans of 5,000 activities or more and can produce output in various forms. However, a computer assists only with the calculation and prints plans of operations sorted into various orders.

The project manager, NOT the computer, is still responsible for the planning and must still make decisions based on the information supplied by the computer. Computer output is only as accurate as its input, supplied by people.

ELEMENTS OF SCHEDULING

A network represents any sequencing of priorities among the activities that form a project. This sequencing is determined by hard or soft dependencies. Hard dependencies are based upon the physical characteristics of the job, such as the necessity for placing a foundation before building walls. A hard dependency is normally inflexible. Soft dependencies are based upon practical considerations of policy and may be changed if circumstances demand; for example, the decision to start at the north end of a building rather than the south.

In constructing networks, there are two types of diagramming techniques that you can apply: precedence (relatively new) and arrow diagramming. The questions often asked by users are: "What is the difference?" and "What should we be using?" Since the project management system accommodates both methods with ease, the choice of method comes down to which is the least complicated and most efficient to implement. The Naval Construction Force (NCF) has converted to the precedence diagram method.

BASIC PRECEDENCE SCHEDULING

Networking procedures are based upon a system that identifies and schedules key events into precedence-related patterns. Since the events are interdependent, proper arrangement helps monitor the independent activities and evaluate progress to complete the project on time. The basic concept is known as the critical path method (CPM). Because the CPM places great emphasis upon task accomplishments, a means of activity identification must be established to track an activity's progress. The methods currently in use are the arrow diagramming method (ADM) and the activity-on-node precedence diagramming method (PDM).

Comparison to Arrow Diagram

The precedence method differs considerably from the arrow-diagram method, since the

operations are shown at the ends of the lines rather than on the lines or the arrows. In precedence networks, lines are used to show dependencies of work items only and not to represent the operation itself.

A precedence network also differs from an arrow-diagram network in that the precedence network does not have the extraneous activities in arrow diagrams. A precedence network does not need dummy or restraint activities. Yet, the sequence of a construction project can be diagrammed to reflect identical logic using either an arrow-diagram or a precedence network.

Conventions for number differ considerably between an arrow-diagram and a precedence network. Arrow-diagram activities are identified with a number that must fit within a certain

increasing sequence. An identification number for precedence activities, however, need only be unique for each activity. Generally, a precedence activity may be identified by any code selected by the planner. If new activities are added or the logic is changed, it is not necessary to renumber the existing activities.

Figure 5-8 shows a comparison between arrow and precedence diagrams. Note in item number 3 that a dummy arrow is required to maintain logic and unique code numbers for arrow activities.

Precedence Diagramming

Precedence diagramming does not require the use of dummy activities, is easier to draw, and has greater applications and advantages when

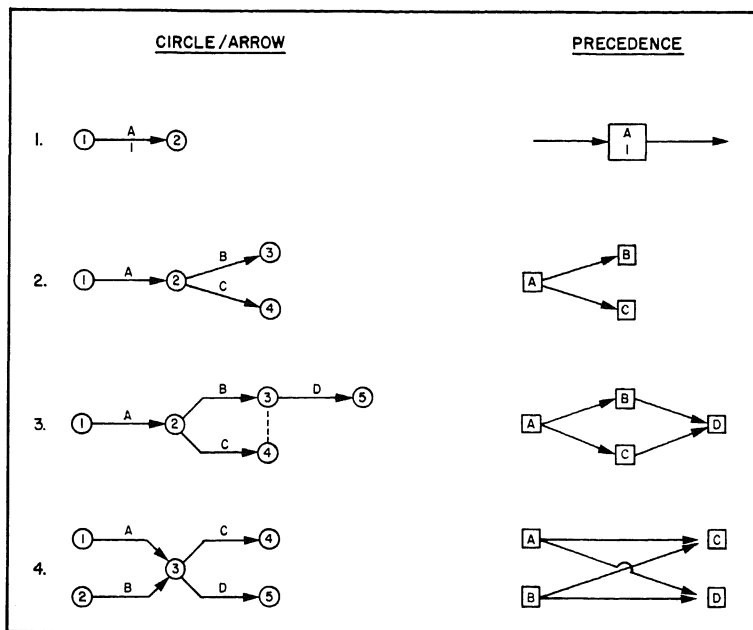


Figure 5-8.—Diagram comparison.

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networks are put on the computer. In precedence diagrams, the activity is on the node, as illustrated in figure 5-9; it is not on the arrow, as is the case with arrow diagramming.

ACTIVITIES AND EVENTS.—To build a flexible CPM network, the manager must have a reliable means of obtaining project data that gets represented graphically by an activity node.

An activity in a precedence diagram is represented by a rectangular box. It is identified by an activity number and not the start and finish nodes as in an arrow diagram. This eliminates the need for additional activities, called dummies, for the purpose of achieving positive identification.

The left side of the activity box represents the start of the activity and the right side represents the completion. Lines linking the boxes are called connectors. The general direction of flow is evident in the connectors themselves, and arrowheads are not necessary.

Activities may be divided into three distinct groups.

- | | |
|------------------------|---|
| 1. Working Activities | Those activities that relate to particular tasks. |
| 2. Milestone Events | Intermediate goals with no time duration but that require completion of prior events before the project can proceed. |
| 3. Critical Activities | Those activities that together comprise the longest path through the network. This is represented by a heavy or hash-marked line. |

The activities are logically sequenced to show the activity flow for the project. The activity flow can be determined by answering the following questions.

1. What activities must precede the activity being examined?
2. What activities can be concurrent with this activity?
3. What activities must follow the activity?

Working Activities.—With respect to a given activity, these representations indicate points in time for the associated activities. Although the boxes represent activities, they do not represent time and, therefore, are not normally drawn to scale. They only reflect the logical sequence of events.

Milestone Events.—The network may also contain certain precise, definable points in time, called events. Examples of events are the start and finish of the project as a whole. Events have no duration and are represented by oval boxes on a network. A precedence network is illustrated in figure 5-10.

Milestones are intermediate goals within a network. For instance, Ready for Print is an important event that represents a point in time but has no time duration of its own. To reach this particular activity, all activities leading up to it must be completed.

Critical Activities.—A critical activity is an activity within the network that has zero float. The critical activities of a network make up the longest path through the network (critical path) that controls the project finish date. The

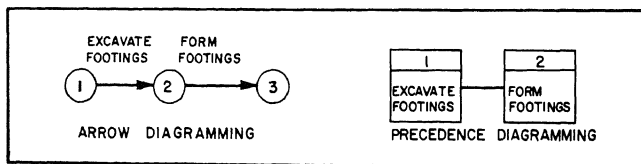


Figure 5-9.—Representation of arrow and precedence diagrams.

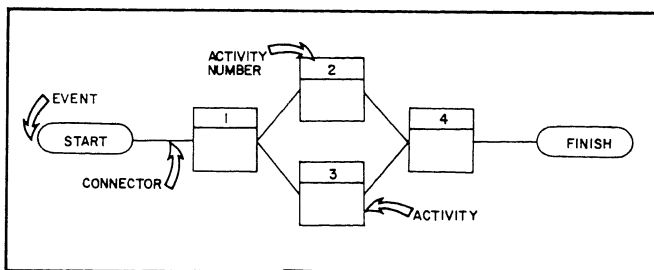


Figure 5-10.—Precedence diagram.

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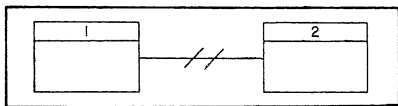


Figure 5-11.—Designation of critical path.

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slashes drawn through the activity connector, as shown in figure 5-11, denote critical path.

The rule governing the drawing of a network is that the start of an activity must be linked to the ends of all completed activities before that start may take place. Activities taking place at the same time are not linked in any way. In figure 5-10, both activity 2 and activity 3 start as soon as activity 1 is complete. Activity 4 requires the completion of both activities 2 and 3 before it may start.

USE OF DIAGRAM CONNECTORS.—

Within a precedence diagram, connectors are lines drawn between two or more activities to establish sequence logic. The diagram connectors commonly used in the NCF are discussed in the following paragraphs.

Representing a Delay.—In certain cases there may be a delay between the start of one activity and the start of another. In this case the delay may be indicated on the connector itself, preceded by the letter *d*, as has been done in figure 5-12. Here activity 2 may start as soon as activity 1 is complete, but activity 3 must wait 2 days. The delay

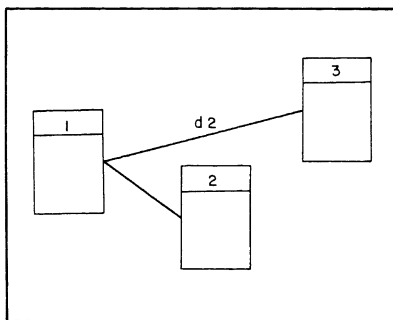
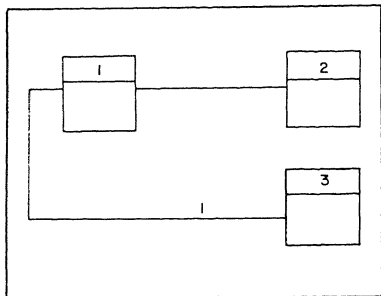


Figure 5-12.—Representation of delay.

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is stated in the basic time units of the project, so the word *days* can be omitted.

Representing a Parallel Activity.—Some activities may parallel others, as illustrated with arrow networks. This can be achieved in precedence diagrams without increasing the number of activities. For instance, it is possible to start laying a long pipeline before the excavations are completed. This type of overlap is known as a *lead*. It is possible to start a job independently, but not to complete it before another is completed. This type of overlap is known as a *lag*. (It is also a common occurrence that both the start and the finish of two activities may be linked, but, in this case, are accommodated by a combination of lead and lag.)

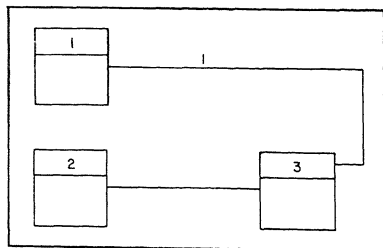


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Figure 5-13.—Lead on start of preceding activity.

As seen in figure 5-13, a lead (or partial start) is indicated by drawing the connector from the start of the preceding activity (1); in figure 5-14, a lag (or partial finish) is indicated by drawing the connector from the end of the following activity (3). The values may be given in the basic time units of the project, as with a delay, or as a percentage overlap. In certain circumstances, it could also be stated as a quantity, if the performance of the activity can be measured on a quantitative basis. The indication of the type and amount of delay, lead, or lag is generally referred to as a lag factor.

In figure 5-13, activity 3 may start when activity 1 is 1-day completed, although activity 2 must wait for the final completion of activity 1. In figure 5-14, activity 3 may start when activity 2 is completed, but will still have 1 day to go when



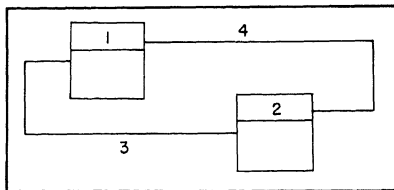
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Figure 5-14.—Lag on finish of following activity.

activity 1 is completed. The last phase of activity 3 may not begin until activity 1 has been completed. In figure 5-15, activity 2 may start when activity 1 is advanced 3 days, but will still have 4 days of work left when activity 1 is completed.

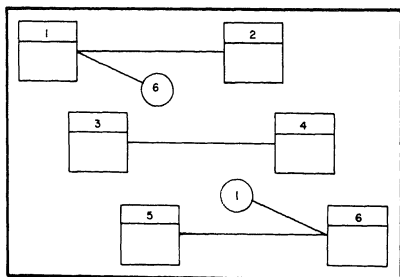
Splitting Connectors.—The number of sequencing connectors becomes very large when a network is of a great size. When two activities are remote from each other and have to be connected, the lines tend to become lost or difficult to follow. In such cases it is not necessary to draw a continuous line between the two activities. To show their relationship, circles are used with the following-activity number in one and the preceding-activity number in the other. In figure 5-16, both activities 2 and 6 are dependent upon activity 1.

Direct Linking Using an Event.—When the number of common preceding and succeeding



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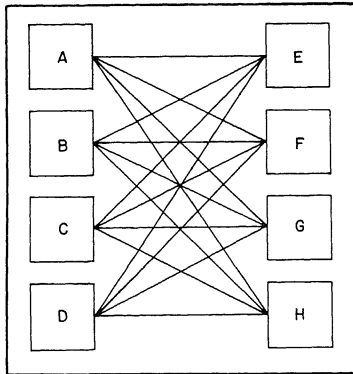
Figure 5-15.—Start and finish lags on same activity.



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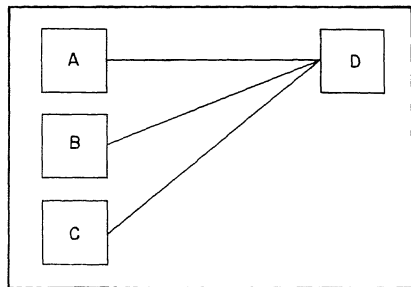
Figure 5-16.—Splitting connectors.

activities in a particular complex is large, as in figure 5-17, a dummy event or focal activity of zero duration may be introduced to simplify the network. The use of such a dummy event is shown in figure 5-18, which is a simplification of figure 5-17. The effect terms of scheduling is the



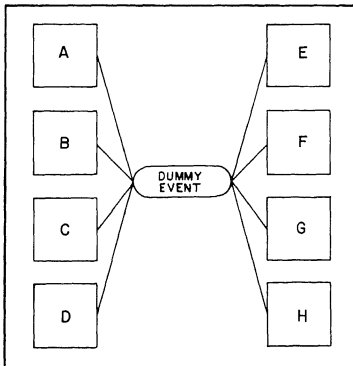
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Figure 5-17.—Multiple predecessors and successors (direct linking).



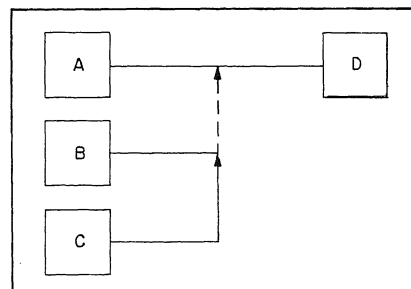
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Figure 5-19.—Direct representation of dependencies.



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Figure 5-18.—Multiple predecessors and successors (using dummy collector).



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Figure 5-20.—Indirect linking of dependencies.

same, but it can be seen that the introduction of the dummy has improved the clarity of the diagram.

Joining Connectors.—In many instances, opportunities are present for joining several connectors going to a common point to reduce the congestion of the drawing. The diagrams in figures 5-19 and 5-20 have precisely the same interpretation. The danger with the form of representation in figure 5-20, where several connectors have been joined, is that when the network is coded for the computer, sight may be lost of the fact that activity *D* has three preceding activities, since only one line actually enters activity *D*. For this reason, this practice must be discouraged.

SCHEDULING PRECEDENCE DIAGRAMS

Scheduling, or putting the network on a working timetable, will be discussed in this section. The information relating to each activity is contained within an activity box, as illustrated in figure 5-21.

Network Time/Duration Computations

To place the network on a timetable, you must figure time and duration computations for the entire project. These computations will establish the critical path and provide the start and finish dates for each activity.

Each activity in the network can be associated with four time values.

Early Start (ES) = Earliest time an activity may be started

Early Finish (EF) = Earliest time an activity may be finished

Late Start (LS) = Latest time an activity may be started and still remain on schedule

Late Finish (LF) = Latest time an activity may be finished and still remain on schedule

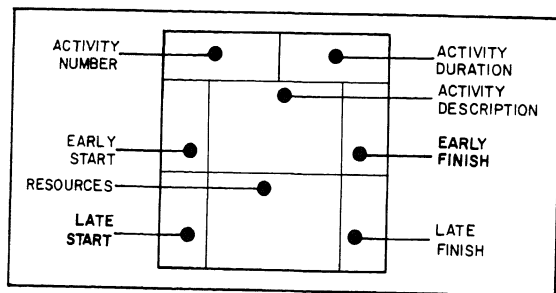


Figure 5-21.—Information for a precedence activity.

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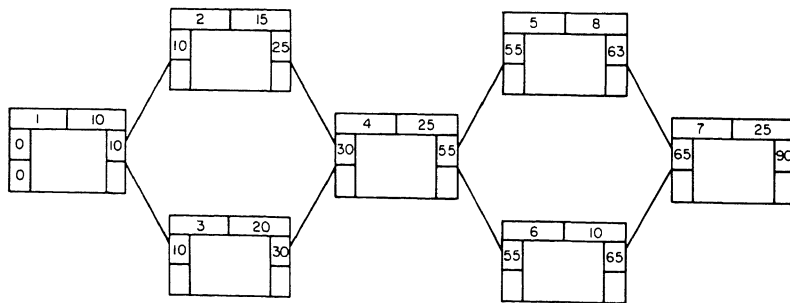


Figure 5-22.—Example of forward pass calculations.

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THE FORWARD PASS.—The main objective of forward pass computations is to determine the duration of the network. The forward pass establishes the early start and finish of each activity and determines the longest path through the network (critical path).

The common procedure for calculating the project duration is to successively add activity durations, as shown in figure 5-22, along chains of activities until a merge is found. At the merge, the largest sum entering the activity is taken as the start of succeeding activities. Addition continues to the next point of merger and the step is repeated. The formula for forward pass calculations is as follows.

$$ES = EF \text{ of Preceding Activity}$$

$$EF = ES + \text{Activity Duration}$$

THE BACKWARD PASS.—Backward pass computations provide the latest possible start and finish times that may take place without altering the network relationships. These values are obtained by starting the calculations at the last activity in the network and working backward, subtracting the succeeding activity's duration from the early finish of the activity being calculated. When a "burst" of activities emanating from the same activity is encountered, each path is calculated and the smallest or multiple value is recorded as the late finish.

The backward pass is the opposite of the forward pass. During the forward pass, the early start is added to the activity duration to become the

early finish of that activity. During the backward pass, the activity duration is subtracted from the late finish to provide the late start time of that activity. This late start time then becomes the late finish of the next activity within the backward flow of the diagram.

$$LS = LF - \text{Activity Duration}$$

Figure 5-23 shows a network with forward and backward pass calculations entered.

FREE AND TOTAL FLOAT.—The amount of scheduled leeway allowed for a network activity is called *float* or *slack*. For each activity, it is possible to calculate two float values from the results of the forward and backward passes.

1. Total Float = The accumulative time span in which the completion of all activities may occur and not delay the termination date of the project. If the amount of total float is exceeded for any activity, the project end date extends to equal the exceeded amount of total float.

Calculating the total float consists of subtracting the earliest finish date from the latest finish date.

$$\text{Total Float} = LF - EF$$

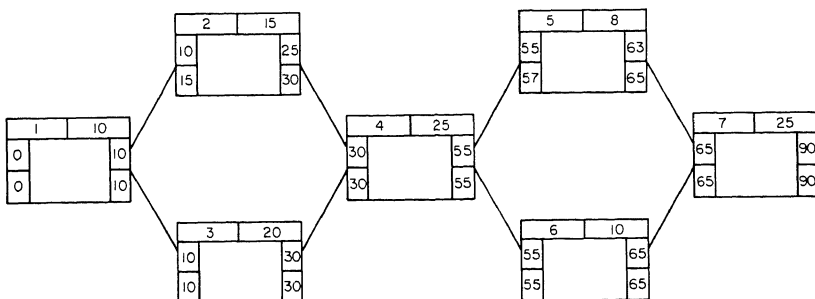


Figure 5-23.—Example of forward pass and backward pass calculations.

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2. Free Float = The time span in which the completion of an activity may occur and not delay the finish of the project or the start of a successor activity. If this value is exceeded, it may not affect the project end date but would affect the start of succeeding, dependent activities.

Calculating the free float consists of subtracting the earliest start date from the latest start date.

$$\text{Free Float} = \text{LS} - \text{ES}$$

Figure 5-24 is an example of an activity-on-node precedence diagramming method (PDM) network with total and free float calculations completed.

Basic Logic Patterns

The graphical representation of an activity is a node. These nodes should not be confused with vectors as used in many engineering disciplines. The node may be square, rectangular, or round to suit the needs of the model; however, the graphical representation should use a standard form throughout the network.

INDEPENDENT ACTIVITY.—An independent activity is an activity that is not dependent upon another activity to start. Activity 1, diagrammed in figure 5-25, is an example of an independent activity.

DEPENDENT ACTIVITY.—A dependent activity is an activity that is dependent upon one or more preceding activities being completed before it can start. The relationship in figure 5-26 states that the start of activity 2 is dependent upon the finish of activity 1.

MERGE.—Frequently an activity cannot start until two or more others have been completed.

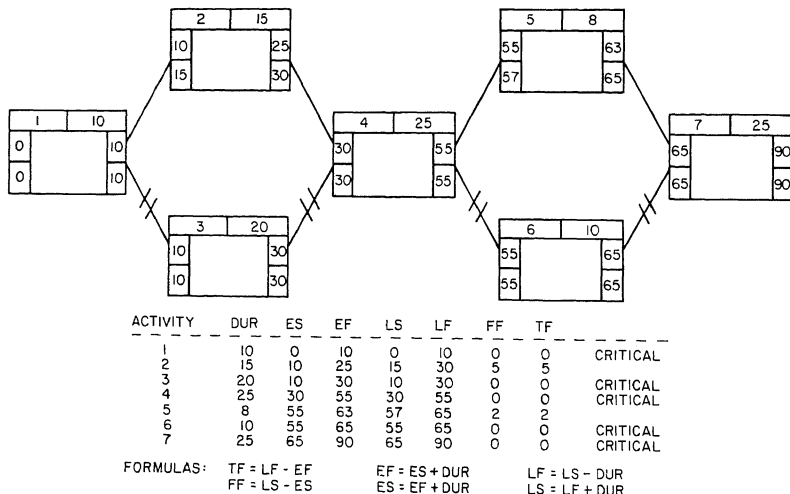


Figure 5-24.—PDM network with total and free float calculations.

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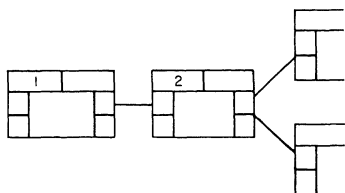


Figure 5-25.—Independent activity.

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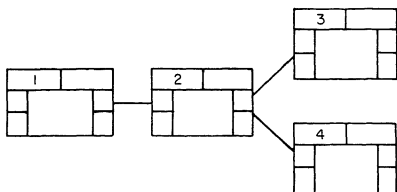


Figure 5-26.—Dependent activity.

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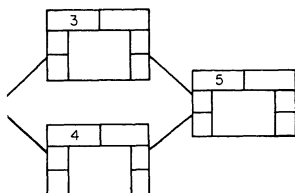


Figure 5-27.—Merge.

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This appears in the diagram as a merge or junction. In figure 5-27, activities 3 and 4 must be completed before the start of activity 5.

BURST.—A burst is similar to a merge. A burst exists when two or more other activities cannot be started until a third activity is completed. In figure 5-26, when activity 2 is finished, activities 3 and 4 may start.

ADVANTAGES OF PRECEDENCE DIAGRAMS

Precedence networks eliminate many of the complicating factors of arrow networks. Most construction management programs for computers are limited by the number of activities the computer can accommodate. Arrow networks may contain 30 percent or more of dummy activities or split activities and are, therefore, very costly to run on computers.

Precedence networks are easier to draw because all the activities can be placed on small cards, laid out on a flat surface, and manipulated easily until a realistic logic is achieved. Draw lines (connectors) to each of the activities to show the relationship between the activities. Figure 5-28 (a foldout at the end of this chapter) represents a typical precedence diagram for a 40- by 100-foot rigid-frame building.

MINICOMPUTER USE IN THE NCF

The usefulness of the minicomputer as a construction management tool for the NCF was first tested in September 1976 during the deployment of NMCB-3 to Diego Garcia. The results were encouraging and the decision was made to install a system at each of the permanent deployment sites, each homeport regiment, the Commander, Construction Battalion, Atlantic (COMCLANT), and the Civil Engineer Support Office. In 1982, the Navy bought an improved version of the original software package for construction management, the CM-5.

Minicomputer use by the private construction industry has increased since the NCF purchased its first system in 1977. This rapid growth within the private sector was a result of the increasing cost of labor and materials and the decreasing cost of minicomputer hardware and software. Also, the evolution of available construction management software programs has provided the construction manager with the specific scheduling, cost, time, and resource information necessary to plan, organize, direct, and control construction projects.

GENERAL DESCRIPTION

The basic minicomputer system consists of at least two keyboard video display terminals, a central processing unit (CPU), four hard disk cartridge drivers, two floppy 8-inch diskette drives, a high speed dot matrix printer, and a slow speed

daisy wheel character printer. The CM-5 program is a menu-driven construction management minicomputer software program (fig. 5-29). The program is very "user friendly" because the user need not have any prior computer training or programming knowledge. This is made possible by the extensive use of screen menus which display on the terminal screen a list of options from which the user may choose. Each option has an assigned number or else requires a simple yes or no response. As a result, all the information that the user needs to make a decision is clearly shown on the terminal screen in simple English.

Although it is always possible to make mistakes when entering information, the program is written so that most errors are detected by the program and the user is immediately informed that an error has been made. This prevents the user from typing in a set of erroneous numbers or letters that could create problems. If an error is made, the program has an edit feature that allows the user to easily correct the error.

CM-5 FEATURES

The CM-5 program handles all the critical path methods of network analysis in use by the NCF, including the arrow diagramming method (ADM) and the precedence diagramming method (PDM). The NCF, however, has chosen to use the PDM

for those projects that are planned and managed on the minicomputer because of its easier method of input and its greater flexibility in changing the network logic. As is commonly used with the PDM, the user can specify lag factors for any of the connectors and structure the network with multiple starts and finishes.

The CM-5 program has a built-in 10-year calendar that is used to determine specific start and finish dates of activities once the project start date is specified by the user. The CM-5 program also takes into consideration an unlimited number of holidays or nonworkdays that the user may specify, and no activities are scheduled to occur on such dates.

Besides being able to specify holidays and nonworkdays, the user can also specify the normal workweek for each activity, whether it is a normal workweek of Monday to Friday or a special workweek of Monday to Sunday, as in the case of a cure activity.

The user can also specify milestones for each activity to allow the user to COMPARE actual progress against established milestones. For example, if the completion of a specific phase or part of a building represents a significant event in the completion of the project, the completion of that activity could be set up as a milestone. As a result, the project manager can see how actual progress is being made toward that milestone.

A similar feature is the ability of the user to specify a specific date on, before, or after the date a particular activity must be started or finished. This is referred to as placing start and finish constraints on activities as the result of a user-imposed constraint. For example, if a certain activity had to be finished by a certain date, the user could place a constraint on that activity so that when the network was processed, the activity would be scheduled to finish on that date.

The program also allows the user to establish a list of available resources (called a resource library) that will be needed on the project.

There is no limit to the number of activities the user can specify for a particular project. However, the number normally used for NCF projects seldom exceeds 150 activities. For each activity the user can specify a maximum of six different resources.

The CM-5 program also has a complete audit trail feature that records all changes (edits) and updates to the network data file. This feature is useful for keeping a written record if the network data file has to be re-created.

```

------(Main Menu)-----
NETWORK TITLE = ADMINISTRATION BUILDING RR-89
NETWORK IS NOT RANKED

FUNCTIONS AVAILABLE:
*****
* (1).....INPUTS TO NETWORK *
* (2).....EDIT DATA ON NETWORK *
* (3).....PROCESS NETWORK *
* (4).....UPDATE WITH FIELD INFORMATION *
* (5).....DISPLAY DATA ON SCREEN *
* (6).....PRINT OUT REPORTS *
* (7).....REPRINT PREVIOUSLY STORED REPORTS *
* (8).....CREATE BACKUP OR TARGET FILE *
* (9).....PRINT INPUT FORMS *
* (10).....PRINT OUT CM-5 SYSTEM INFORMATION *
* (0).....END PROGRAM *
*****

ENTER FUNCTION DESIRED ____
-----

```

Figure 5-29.—Main menu.

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PROGRAM OPTIONS AND MENU DISPLAYS

As previously discussed, the program consists of a full set of menus from which the user can easily select a numbered option that tells the program to perform a specific operation. The primary menu and the starting point for any session at the minicomputer is the main menu. The main menu is a list of the major program options available.

Figure 5-29 shows the actual information or main menu that you will see on your computer screen. The main menu displays the project description, such as Administration Building RR-89. The status of the network is also shown and tells the user whether the network is Not Ranked, Not Processed, or Processed. The user has a choice of ten different options from which to choose. Below the list of options, the program displays a prompt that requests the user to select from the available options and enter the number that corresponds to the desired option. The option is entered by typing in the number and depressing the RETURN key on the terminal.

Depending upon what option is entered, the program will automatically take the user to the next screen that will display another menu from which the user must choose.

Option 1: Inputs to Network

The input option is the option through which the user enters specific project data into the minicomputer by the keyboard terminal. In order for the CM-5 program to completely perform its capabilities, the user must first input the following information:

- General Project Information
- Resources
- Activities
- Connectors (Logic)
- Milestones (Events)

To make this procedure easier, the user should use the input sheets produced by option 9 (discussed below) of the main menu. The input sheets show the specific information needed and places the information in the order it will be requested.

Option 2: Edit Data on Network

The CM-5 program allows the user to use the edit option to change or correct any item of information in the network data file. Through this option, the user can have the program display on the screen any item of information desired and edit the item at any time.

It is a common mistake for inexperienced users to confuse the edit option with the update option. The edit option is used to CHANGE or CORRECT information after input to make sure the information entered does not contain any mistakes. In simple terms, it helps the user prevent putting "garbage" into the minicomputer so "garbage" will not be produced later when the network is processed.

When using the edit option, the user must be aware that some changes to certain items of information will affect network status. As previously discussed, the network status will be either unranked, unprocessed (ranked), or processed. Since the ranking and processing procedures can be time consuming, the user should exercise care when using the edit option so the network status is not changed unnecessarily.

Option 3: Process Network

Once the user has input the required information and has performed any required edits to ensure the information is correct, the next step is for the user to use the process option to have the CM-5 program perform the network calculations to determine the early and late activity dates, and free and total float. In short, the process option causes the CM-5 program to perform the forward and backward passes for the network. Besides determining the network schedule, the process option also calculates the man-days and resource requirements for the project.

The processing procedure, while faster than doing the calculations by hand, can take what may appear to the user as a long time. The length of time it takes to process the network is primarily a factor of the number of activities and the project duration. The average NCF project will process in less than 15 minutes.

Option 4: Update with Field Information

Once the network information has been input, edited, and processed, the user is ready to use the network to manage the particular project on

deployment. The update option is the manner by which the user informs the minicomputer of the ACTUAL start and finish dates, man-days, and resource usage for each activity once on the deployment site.

Actual project progress is entered in the update option to keep the plan up-to-date for each activity that was worked on before the update date.

Once the user updates the network data file with the information for those activities that have been worked on, the CM-5 program will reprocess the network and provide the user with a new schedule that shows the effect of the actual activity information. For example, if the update shows an activity took longer than originally planned, then the starting dates and floats of all activities that follow will be changed to reflect the delay.

The update option is the key to successful use of the CM-5 program. If the program is to be effectively used to monitor and control the project on the deployment, the battalion must establish a uniform policy and procedure for updating the network data file with actual time, man-days, and resources usage date(s).

Option 5: Display Data on Screen

The display option allows the user to view specific network data on the terminal screen. By looking at the information on the terminal screen, the user is saved the time normally spent requesting that a copy of the information be printed out on the printer. This saves a considerable amount of paper, as well as time.

The range of items the user can view on the screen is indicated by the list of functions the user can choose from on the network display menu, shown in figure 5-29.

Option 6: Print Out Reports

The CM-5 program is capable of producing for the user a full set of printout reports. The user also has the capability to use activity attributes to select and sort specific items of information so the report contains only that information necessary for the project manager to make a decision.

As in all cases where the user must input data, the CM-5 program also has a full set of menus the user can use to easily select and sort any one of the 25 reports that is available. The activity select and activity sort menus list the various activity attributes the user can use for structuring reports.

As is true for all menus displayed by the CM-5 program, the user need only enter the number that corresponds to the item of interest and depress the RETURN key.

Option 7: Reprint Previously Stored Reports

Option 7 allows the user to save (store) the list of commands that were used to select, sort, and print out a set of reports. This can speed up the process by which a set of reports is obtained. For example, on deployment the operations department may set up a series of reports it wants to print out at the end of each week. Instead of typing in the list of select, sort, and report commands for the report option, the operations department can have the list of commands saved and use the reprint option. This would not only save time but would also ensure that the same series of reports in the desired format were made available each week.

When this option is used, only one set of reports can be saved. Each time a series of select, sort, and report commands are saved, any previously saved list of commands is erased from the file and is unable to be used further.

Option 8: Create Backup or Target File

Option 8 allows the user to make a copy of the network data file for future use should the working file become damaged or destroyed. The working file is the file that is being regularly used to plan and manage a project. Also, this option allows the user to make a target file for use during the deployment to compare the planned network against the actual network. A target file is a copy of the network data file that can be made at any time and used to compare the current schedule with the target schedule.

It is a good procedure to always make a backup copy of a working file whenever any changes are made to the working file.

Option 9: Print Input Forms

The CM-5 program allows the user to print out copies of each of the input forms that are used to list the information needed to establish a network data file.

Option 10: Print Out CM-5 System Information

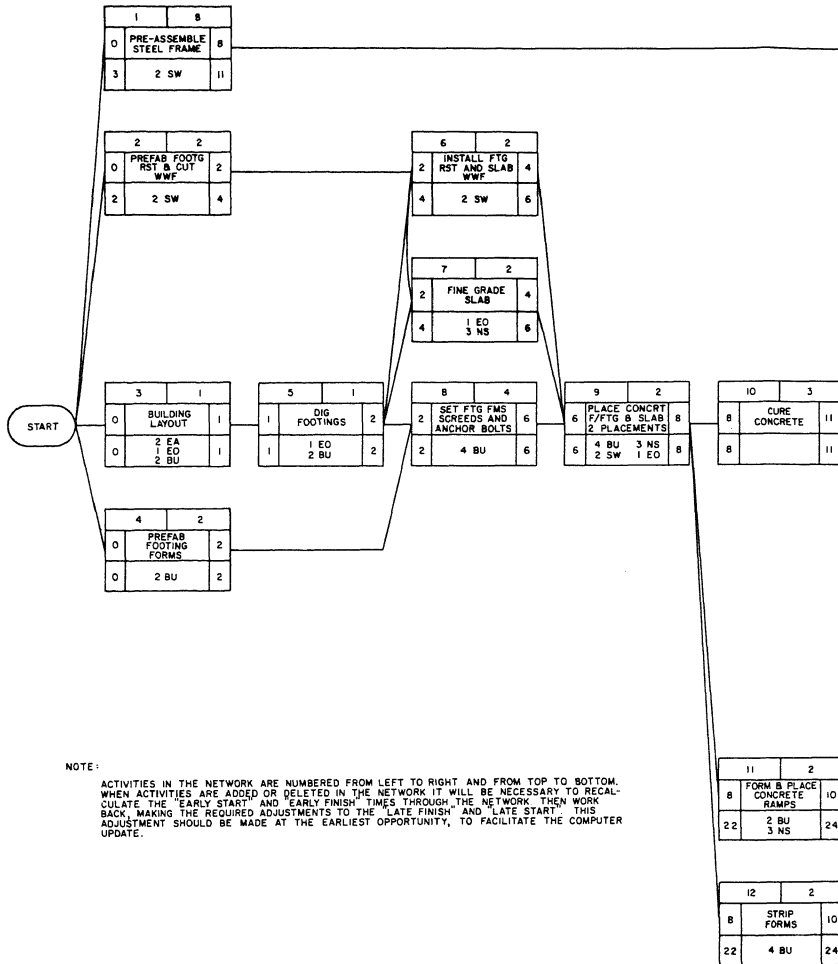
Option 10 is used to print out a form letter by which the user can inform the software

developer, Structural Programming Inc., of any problems that may be encountered when the CM-5 program is used.

CHAPTER REFERENCES

Facilities Planning Guide, NAVFAC P-437, Naval Facilities Engineering Command, Alexandria, Va. 22332, 1982.

SEABEE Planner's and Estimator's Handbook, NAVFAC P-405, Chapter 5, Naval Facilities Engineering Command, Alexandria, Va. 22332, October 1983.



CHAPTER 6

ADVANCED BASE PLANNING, EMBARKATION, AND PROJECT TURNOVER

Learning Objective: Identify the principles involved in the use of the Facilities Planning Guide; identify procedures used in preparing material and equipment for embarkation and for project turnover.

This chapter discusses the principles of using the *Facilities Planning Guide*, which is an advanced base planning document. Guidelines are provided for a system of preparing material, equipment, and personnel for embarkation. Information is also presented on how you can best coordinate and supervise the turnover of the company's projects, material, and equipment.

FACILITIES PLANNING GUIDE

You should consult the *Facilities Planning Guide* (NAVFAC P-437) when tasked to assist in planning the construction of an advanced base. This document identifies the structures and supporting utilities of the Navy advanced base functional component (ABFC) system. It was developed to make preengineered facility designs and corresponding material lists available to planners at all levels. While these designs relate primarily to expected needs at advanced bases and to the Navy ABFC system, they can also be used to satisfy peacetime requirements. Facilities, logistic, and construction planners will each find the information required to select and document the material necessary to construct facilities.

NAVFAC P-437 consists of two volumes. Volume I contains reproducible engineering drawings organized as follows:

Part 1, Component Site Plans, indexed by component and ABFC designation.

Part 2, Facility Drawings, indexed by facility number and DOD category code.

Part 3, Assembly Drawings, containing assembly information and indexed by assembly number.

Each drawing is a detailed construction drawing that describes and lists the facilities,

assemblies, or line items required to complete it. A summary of logistic, construction, and cost data is provided for each component, facility, and assembly of the ABFC system. A component is defined as a grouping of personnel and material that has a specific function or mission at an advanced base. Whether located overseas or in CONUS, a component is supported by facilities and assemblies.

Volume II of NAVFAC P-437 contains the detailed data display for each component, facility, and assembly. (Except for earthwork, material lists in volume II are complete bills of material.) It is also arranged in three parts.

Part 1 lists and describes by DOD category code the facilities requirement for each component.

Part 2 lists and describes by assembly number the assembly requirement for each facility.

Part 3 lists line-item requirements by national stock number (NSN) for each assembly.

The P-437 also contains other useful information for planners; for example, crew sizes, man-hours by skill, land areas, and the amounts of fuel necessary to make a component, facility, or assembly operational, and predesigned facilities and assemblies that are not directly related to components shown in the ABFC table (OPNAV P-41P3A). These predesigned facilities and assemblies give the planner alternatives for satisfying contingency requirements when callout of a complete component is not desired. To make the P-437 compatible with other DOD planning guides, *Category Codes for Classifying Real Property of the Navy*, NAVFAC P-72, is a related publication that establishes the category codes, nomenclature, and the required units of measure for identifying, classifying, and quantifying real

property. The cardinal category codes are as follows:

100	Operations and Training
200	Maintenance and Production
300	Research, Development, and Evaluation
400	Supply
500	Hospital and Medical
600	Administrative
700	Housing and Community Support
800	Utilities and Ground Improvement
900	Real Estate

If a facility is required for enlisted personnel quarters, for example, it will be found in the 700 series (Housing and Community Support). The assemblies within each facility consist of a grouping of line items at the NSN level which, when assembled, will perform a specific function in support of the facility. An assembly is functionally grouped in such a way that the assembly number relates to the Occupational Field 13 skill required to install it. The groupings are numbered as follows:

<u>DESCRIPTION</u>	<u>NUMBER</u>	<u>SEQUENCE</u>
	<u>START</u>	<u>STOP</u>
Builder (BU) oriented	10,000	19,999
Utilitiesman (UT) oriented	20,000	29,999
Construction Electrician (CE) oriented	30,000	39,999
Steelworker (SW) oriented	40,000	49,999
Equipment Operator (EO) oriented	50,000	54,999
Waterfront equipment	55,000	57,999
Underwater construction and diving equipment	58,000	59,999
Operational supplies	60,000	62,499
Operating consumables	62,500	64,999
NBC warfare	65,000	67,499
Personnel-related supplies	67,500	69,999
Unassigned at present	70,000	79,999
Shop equipment including maintenance tools	80,000	80,999
Unique ABFC toolkits	81,000	81,999
Naval Construction Force (NCF) Table of Allowance (TOA) construction tools and kits (power tools)	82,000	82,099
NCF TOA construction tools and kits (electrical)	82,500	82,599
NCF TOA construction tools and kits (miscellaneous)	83,000	83,199

<u>DESCRIPTION</u>	<u>NUMBER</u>	<u>SEQUENCE</u>
	<u>START</u>	<u>STOP</u>
NCF TOA construction tools and kits (rigging)	84,000	84,099
Shop equipment (ABFC unique)	85,000	87,499

TAILORING COMPONENTS AND FACILITIES

When you consider tailoring, it is important to realize that the ABFC system is based on a set of assumptions. This realization makes it possible to develop modular elements that can serve similar functions in various locations. The exact requirements for a specific base cannot be defined, economically designed, nor supported within the general system. However, the base development planner knows the specific location, mission, unit composition, and availability of other assets. The planner can then select from the ABFC system the components or facilities that satisfy these requirements. Tailoring is then applied to the preplanned ABFC assets to come up with what is needed.

Components or facilities can be tailored by (1) deleting or adding facilities or assemblies and (2) specifying requirements for tropical or northern temperate zones. Assemblies required only in tropical installations are coded with the letter *T* in the zone column to the right of the assembly description. Assemblies required only in northern temperate installations are coded with the letter *N*. Uncoded assemblies are common to both zones.

USE AND APPLICATION OF THE FACILITIES PLANNING GUIDE

Although a listing in the P-437 may help you order individual items in general supply, it does not replace stock lists of systems commands or bureaus, offices, single managers, or inventory control points. Stock numbers and descriptions can be verified through appropriate stock lists. However, you verify them automatically in ordering a component, facility, or assembly.

A representative sample of component types displayed in volume II shows the structure and kind of information provided. Figure 6-1 shows a P-25 component, Naval Mobile Construction Battalion. You can see that a component contains a list of facilities by category code. From this list select a facility, such as diesel storage and dispensing facility, 200,000-gallon, facility 123-10F. Locate this facility in part 2 of volume II. Figure 6-2

COMPONENT P25									
NAVAL MOBILE CONSTRUCTION BATTALION									
PROVIDES PERSONNEL ADMINISTRATION ASSISTANCE EQUIPMENT AND MINIMAL HOUSING REQUIRED FOR THE MOBILIZATION OF ONE MOBILE CONSTRUCTION BATTALION.									
SITE PLAN 6027843									
MAJOR REV 11 12 76									
FACILITY	DESCRIPTION	CAPACITY	QTY	COMPONENT	HEIGHT FEET	WEIGHT TON	CUBIC FEET	DOLLAR VALUE	CONST EFFORT MANHOURS
123 10A	MORGAS STORAGE-DISPENSING FACILITY	1 OL	1	1 OL	5.4	23.5	48,832	208	
123 10B	DIESEL STOR-DISPND FACIL 200000 GAL	1 OL	1	1 OL	8.7	35.9	88,108	484	
142 45E	ARMORY CENTER/ILLER	210 SF	1	210 SF	7.6	82.2	14,081	175	
214 20N	A CO AUTO VEHICLE SHOP	4000 SF	1	4000 SF	5.1	11.1	23,450	108	
214 10A	WEAPONS REPAIR CENTER/ILLER	210 SF	1	210 SF	4.5	76.7	12,495	48	
218 20A	A COMPANY CONSTRUCTION EQUIP SHOP	4000 SF	1	4000 SF	5.1	11.0	23,257	108	
218 10B	B & C AND O COMPANY SHOP/ILLER	1872 SF	1	1872 SF	5.4	12.1	28,163	82	
218 10M	CENTRAL TOOL ROOM (MINIMUM)	4000 SF	1	4000 SF	1.7	5.3	10,831	48	
244 10S	WAREHOUSE GENERAL STORAGE RM	4000 SF	3	12000 SF	3.9	12.0	24,910	120	
230 10B	MEDICAL/FIRST AID INITIAL	936 SF	2	1872 SF	5.8	12.6	8,345	110	
240 10D	DENTAL CLINIC BENT-TRAILER MOUNTED	2 DU	1	2 DU	10.1	104.7	93,189	180	
240 10PS	SPECIAL SERVICES/POST OFFICE	936 SF	1	936 SF	6	2.5	3,173	33	
250 10V	OFFICE ADMINISTRATIVE MINIMAL	238 SF	10	2380 SF	6.0	63.0	3,122	200	
725 10AH	GALLERY MESS FIELD W/CHINA BUFF-PRZR	500 MM	1	800 MM	62.8	287.3	237,145	1,027	
722 10BH	BAKERY PLANT FIELD PORTABLE	1500 MM	1	1500 MM	2.9	6.5	4,238	61	
723 80BX	EXCHANGE-BARBER SHOP	936 SF	1	936 SF	6	2.5	3,173	30	
723 61A	SHOWER TRAILER 24-SHOWER HEAD C/D	EA	6	6 EA	13.8	42.8	94,800	102	
725 10V	TROOP HSG ENRG W/OUT WASHROOMS	3744 SF	2	7488 SF	8.2	28.0	27,119	320	
723 10V	TROOP HSG ENRG W/O SHOWERS ENLIST	8424 SF	6	50544 SF	80.6	201.6	185,554	2,424	
725 10VQ	QUARTERS FTR DTY	5832 SF	1	5832 SF	17.4	38.3	30,312	88	
730 40M	LAUNDRY TRAILER-MOUNTED	280 SF	1	280 SF	9.9	15.0	92,721	101	
811 10AV	ELECTRIC POWER PLANT DIESEL 2-200KW	400 KW	1	400 KW	11.9	16.7	111,911	108	
812 30PC	ELECTRICAL DISTRIBUTION LINE-EXPPD	2000 LF	1	2000 LF	30.8	38.8	222,233	2,270	
831 30A	LEACH FIELD	EA	3	3 EA	1.2	9.7	1,581	366	
841 10M	WATER TREATMENT FACILITY 1500 GPM	30 EG	2	60 EG	11.0	19.0	33,825	82	
841 40M	WATER TREATMENT POTABLE	3000 EG	1	6000 EG	8.0	10.8	32,880	124	
841 10J	WATER DISTRIBUTION LINE POTABLE	7640 LF	1	7640 LF	10.1	27.7	41,400	480	
851 10B	ROAD UNSTABILIZED W/DRAINAGE	33088 LY	1	33088 LY	29.2	14.2	8,142	277	
872 10B	SECURITY FENCING	1880 LF	4	7520 LF	28.2	88.4	30,315	4,158	
872 200	BUNKER COMMAND POST	1 EA	3	3 EA	36.9	44.1	17,681	2,652	
TOTAL NORTH (TEMPERATE)					378.2	1,279.7	1,582,045	17,018	
TOTAL TROPICAL (BASIC)					383.4	1,238.5	1,500,341	19,688	
COMPONENT P25									
CONST STD	LAPSED DAYS	LAND ACRES	POWER KVA CONNECTED	DEMAND	WATER GPD	SEWER GPD	FUEL GAL/300DAYS	HEATING PER GPM	CONST EFFORT MANHOURS
INIT	0	150.0	360	244	40,363	33,980	65,820	2,864	1,340
SKILLS MANHOURS	EA	BU	UY	CE	SW	EO	CM	NS	
	181	2,457	1,724	2,187	457	4,041	0	5,961	

Figure 6-1.—Component.

87.336

FACILITY 123 10F				PLANNING FACTOR NA							
DIESEL OIL STORAGE AND DISPENSING 200000 GAL											
NAVFAC DRAWING NUMBER NETWORK				MAJOR REV. 03 11 77							
ASSEMBLY	DESCRIPTION	ZONE	QTY	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE	CONST EFFORT MANHOURS				
20002	TANK FUEL PILLLOW 50000 GAL		4	7,898.4	642.2	51,124.44	352				
20124	HOSE HANG F/200000 GAL TANK ARR		1	842.2	55.8	1,854.19	2				
20054	FUEL TRANSFERER ASSEMBLY 350 GPM		1	3,474.8	470.3	13,670.90	44				
20035	FUEL DISPENSING ASSY PORTABLE		1	1,610.1	53.2	6,457.53	36				
20036	NOZZLES DISPENSING STAND		1	1,177.9	73.3	2,798.30	8				
20036	FUEL FILTER AND METER ASSY 600 GPM		1	3,474.8	284.3	12,110.31	42				
SHORT TON				WEAS TON							
TOTAL NORTH (TEMPERATE)				8.7	35.9	17,391.2	1,434.7	86,105.76	484		
TOTAL TROPICAL (BASIC)				8.7	35.9	17,391.2	1,434.7	86,105.76	484		
FACILITY 123 10F				PRIMARY UNIT OF MEASURE				1 OL SECONDARY UNIT OF MEASURE			
CONST STD	LAPSED DAYS	LAND ACRES	POWER KVA	CONNECTED DEMAND	VOLTS PHASE	WATER TOT. GPD	WATER PEAK GPM	SEWER GPD	RECVY. CODE		
TEMP	6	1.28	17	8	208	3	0	0	A		
FUEL GAL/300DAYS											
HEATING PER GPM											
OSL	0	490	0	8	8	108	0	20	324		
SKILLS MANHOURS											
BU				UY		CE		SW	EO	CM	NS
0				16		0		20		16	

Figure 6-2.—Facility.

6-3

87.337

shows this facility. Note that within the facility, the necessary assemblies required to perform the defined function are identified. Figure 6-3 depicts an assembly within facility 123-10F. Within assembly 20002 (titled 50,000-gallon pillow fuel tank), line items by NSN required to make the assembly operative are displayed.

Certain installed equipment and collateral equipment, furniture, and fixtures contributed by others are not furnished with the facilities or the assemblies listed in the P-437. They must be requested separately. The assembly listings indicate what is installed or what NAVFAC collateral equipment is provided.

ADVANCED BASE FUNCTIONAL COMPONENTS

ABFCs are normally complete entities. However, housing, messing, medical facilities, maintenance facilities, defensive ordnance, communication equipment, and utilities may not be supplied with each component and are themselves service components or facilities to be integrated into an overall base development or augmentation plan. ABFCs are assigned descriptive names to indicate their functions and alphanumeric designators to facilitate reference. A detailed advanced base initial outfitting list

(ABIOL) is an itemized line-item printout of the material in each ABFC. Each systems command or bureau is responsible for maintaining a detailed listing of that part of the ABIOL assigned to it.

EMBARKATION

A Navy Mobile Construction Battalion (NMCB), an Amphibious Construction Battalion (PHIBCB), a Construction Battalion Maintenance Unit (CBMU), or any other unit of the Naval Construction Force (NCF) must be ready to deploy or redeploy by sea, air, or land to complete an assigned mission. To meet the requirements for contingency support of the naval task force and the Fleet Marine Force, PHIBCBs and CBMUs must be able to redeploy within 3 and 6 days respectively. After 30 days in home port, other NCF units should be able to redeploy within 10 days. While en route to or from a deployment site, the units must be prepared for immediate diversion to emergency, contingency, or mobilization assignments. While deployed, NMCBs should be able to redeploy within 6 days.

Embarkation planning and preparation of personnel, supplies, and equipment for embarkation to conduct an amphibious operation or air movement are expensive in terms of time and

ASSEMBLY 20002				ZONE		20002			
TANK FUEL PILLOW 50000 GAL									
NAVFAC DRAWING NUMBER 6002614 MAJOR REVISION DATE 03 23 73									
COR	STOCK NUMBER	DESCRIPTION	UI	QTY	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE		
WC	4710-00-273-10A1	PIPE CULV HESTABLE 16 GA AL 12W X 2FT	EA	4	26.40	2.1800	51.84		
WC	4710-00-619-8445	PIPE SIL RI STD W 2N NPT	FT	20	75.00	1.8000	23.50		
WC	4720-00-978-8887	WIDE ASSY NON FUEL-TPH 4N X 10 FT FEN X WALE ODISC	EA	3	191.00	7.5000	626.74		
WC	4730-00-084-0180	REDUCER QUICK DISCONNECT CAN-LOCKING TYPE 4N	EA	1	10.00	.3000	95.72		
WC	4730-00-084-0286	COUPLING HALF ODISC CAN-LOCKING TYPE FEMALE X	EA	2	16.00	.4000	51.58		
WC	4730-00-186-2078	INTERNAL PIPE THROG 4N	EA	1	3.15	.0800	2.31		
WC	4730-01-076-8234	REDUCER ODISC CAN-LOCKING TYPE 4N FEMALE X WALE	EA	1	12.00	.2000	64.47		
WC	4820-00-060-7825	VALVE GATE DIA-OPG 800 2N NPT	EA	1	11.00	.2000	74.69		
WC	5330-00-898-4509	GASKET COUPLING WALE ODISC CAN-LOCKING TYPE 4N	EA	3	.08	0.102	.98		
CC	5430-00-182-4161	1 NYLON CLOTH MATERIAL IMPREGNATED AND COATED 1 TANK AND OUTSIDE WITH POLYURETHANE, 5.677T HIGH 1 8371 LONG, 247 WIDE FILLED	EA	1	1,800.00	125.0000	11,786.00		
ASSEMBLY 20002				TOTAL	1,924.61	136.8102	12,781.11		
FUEL (GAL/30DAYS)				HEATING		PWR GEN		CONST EFFORT	
04	MODS	04	EA	3	1	1	1	HOURS	
0	0	0	2	0	2	0	0	3	
NOTE - CREW SIZE: 2 EA, 1 UT, 4 EO, 3 CW									

Figure 6-3.—Assembly.

manpower. However, the efficiency of embarkation is usually directly proportional to the time and effort spent in developing the plan and preparing for its execution. A well-developed plan usually will reduce time and effort required for embarkation and ensure that the embarkation is orderly, efficient, and effective.

Staff officers responsible for embarkation must ensure that embarkation is executed on schedule in accordance with the time table that has been established by their command or higher authority. Before the embarkation, for example, the medical officer should see that personnel have had their inoculations. Also, the dental officer should place a hold on personnel who need prolonged dental treatment that would limit their combat readiness. The personnel officer should ensure that the Record of Emergency Data, NAVPERS 601-2, and other records are current.

Although not part of an embarkation staff, you are involved in the embarkation of your company. Your tasks include making sure that all projects are shut down, tools are cleaned and turned into the central toolroom, materials are secured on the site or turned into the material liaison office (MLO), and that the project sites are cleaned and secured. These tasks are carried out whether the embarkation is a training exercise or an actual movement. Afterward you should direct your efforts to the embarkation itself. Instructions will come from the embarkation staff's office. The embarkation staff relies on the *Tactical Embarkation Manual*, as developed by the Commander, Construction Battalions, Atlantic (COMCBLANT) and the Commander, Construction Battalions, Pacific (COMCBPAC). This manual is also available to you.

Each company or department that is shipping material should designate one officer or petty officer to act as its embarkation representative. The representative's duties include the following:

1. Keeping the NMCB and team embarkation officers informed of shipping requirements
2. Ensuring that mount-out box construction, color coding, and numbering are in accordance with established directives
3. Ensuring that each box, pallet, or skid required for mount-out is available; new boxes are constructed for additional gear as received
4. Ensuring that packing lists are current and accurate; that new packing lists are prepared for additional gear as received
5. Making available box covers and hardware to attach them to their boxes

6. Ensuring that unit cargo manifests are maintained, reviewed quarterly, and forwarded to the embarkation officer

MOUNT-OUT CONTROL CENTER

The mount-out control center (MOCC), also known as the embarkation control center, controls, coordinates, and monitors the movement of all personnel, supplies, and equipment to the embarkation staging area. The MOCC usually has authority to establish traffic control, issue movement orders to units concerned, and control transportation used in the embarkation mount-out. The MOCC coordinates and schedules the movement of personnel, supplies, and all related equipment from storage areas or warehouses, or from the unit's base camp area to the staging area for embarkation. Within the NMCB, the MOCC, with the embarkation staff, controls all aspects of an NMCB mount-out and serves as the coordinating center for all the companies and all the staff section heads.

Within the NMCB, the executive officer, as chief staff officer, directs the operation of the MOCC. The MOCC may be located in an office or conference room that is provided with adequate telephone and other communications and has suitable space for displays of the progress of the mount-out. The executive officer must have a small staff of personnel trained to handle the communications and to plot the status of the critical items in the embarkation checkoff listings of the principal staff officers and companies.

The MOCC functions as the nerve center during an embarkation. It is absolutely essential that the status of all actions be forwarded to the MOCC on a continuous and timely basis. The MOCC must be informed of all decisions that are made so all personnel with a need to know receive the information.

A preplanned checkoff list of the embarkation responsibilities of each key staff member in the NMCB forms the basis for reporting to the MOCC and the display of status information. Each of the items on this listing should be reported when due, and additional information that has an impact on other parts of the organization must also be reported. Any uncertainty regarding the need to report an item to the MOCC should be resolved in favor of reporting; it is impossible to have the MOCC too well informed.

Embarkation/MOCC files must be set up and kept current in anticipation of an embarkation,

whether scheduled or unscheduled for the NMCB either by surface or air movements. The embarkation staff is responsible for keeping the MOCC files current with all the necessary information on embarkation.

The actual loading of vessels or aircraft is the responsibility of the embarkation officer and the combat cargo officer or loadmaster of the ship or aircraft or their designated representatives. The MOCC must be kept informed as to the progress of loading by the embarkation staff so the embarkation/MOCC can file the required reports to higher authority.

EMBARKATION REPORTS, RECORDS, AND FILES

Upon the completion of any embarkation mount-out, a completion report is sent to COMCBLANT or COMCBPAC as soon as possible under the existing circumstances. The

completion report should include, but not be limited to, the complete corrected load plan, problems encountered during the embarkation, and suggested remedial steps.

When an embarkation exercise is conducted at the direction of the Naval Construction Regiment (NCR), COMCBLANT, or COMCBPAC, a detailed exercise completion report should be submitted within 30 days after the completion of the exercise. The report should contain (but is not limited to) the following:

1. Load plan as submitted to the assigned ship
2. Load plan as actually loaded
3. Summary of problems encountered with recommended corrections in procedures
4. Exercise improvement suggestions
5. Report of support received during the embarkation exercise by all concerned

LOADING STATUS REPORTS

Embarkation team commanders should submit the following message reports to the embarkation group commander for each ship being loaded or unloaded, with an information copy to the embarkation unit commander, the homeport NCR, and COMCBLANT and/or COMCBPAC.

1. India Report

An India report is the initial report submitted upon commencement of loading or unloading. The text format is as follows:

Name of Ship: _____

Charlie Tango: Time Loading/Unloading Commenced

2. Foxtrot Report

A Foxtrot report will be sent upon completion of loading or unloading. The text format is as follows:

Name of Ship: _____

Foxtrot Tango: Actual time of completion of loading/unloading.

3. Romeo Report

Two types of progress reports will be submitted by embarkation commanders. Romeo Alfa will be submitted only when directed and as of 0600, 1400, and 2200 daily. Romeo Bravo will be submitted as occurring when significant events cause excessive delay to the loading/unloading. The text format for the two reports is as follows:

a. Romeo Alfa Report

November: Name of Ship

Papa: Percent Personnel Embarked/Debarked

Victor: Percent Vehicles Loaded/Unloaded

Tango: Estimated Time of Completion of Loading/Unloading

b. Romeo Bravo Report

State exactly the event causing the delay in loading/unloading.

4. Sierra Reports

Sierra reports will be classified in accordance with the degree of security required but NOT lower than **CONFIDENTIAL**. They will be submitted in all instances of embarkation in amphibious/Military Sealift Command (MSC) ships for contingency deployments. These reports are not required for embarkation exercises. The reports will be of two types:

a. Sierra Alfa Report

This report will be a consolidation of all the supplies embarked by the embarkation group or the embarkation unit. NMCBs need not submit the Sierra Alfa report.

b. Sierra Bravo Report

Each embarkation team commander will submit this report by message upon the completion of loading in the following format:

Paragraph One: Name of operation/exercise; Date/Time Group (DTG) ship commenced loading; DTG ship completed loading.

Paragraph Two: Names of all units and detachments embarked, indicating the officer and enlisted strengths of each. Navy and Marine totals will be listed separately.

Paragraph Three: List the number of crew-served weapons, by type.

Paragraph Four: The number by type of wheeled and tracked vehicles.

Paragraph Five: The number and type of aircraft, if assigned.

Paragraph Six: The number by type of all other combat-essential major items of equipment.

Paragraph Seven: Total square feet of vehicles and equipment.

EXAMPLE

FROM: CO TROOPS, *USS CANDO COUNTY*

TO: CG FMFLANT
COMCBLANT
COMPHIBLANT
20TH NCR
CG 2ND MAW

CLASSIFICATION

INITIAL SIERRA BRAVO REPORT

1. EXLANTBEE 6-69. CHARLIE TANGO 120727Z FOXTROT TANGO 122215Z.

- | | | | | |
|-----------------|------|--------|------|-----|
| 2. NMCB-88 | USN | 18/522 | USMC | 0/1 |
| CO A, NMCB 93 | USN | 1/97 | | |
| DET 2ND CA TEAM | USA | 4/10 | | |
| CO B, 8TH ENGR | USMC | 4/230 | | |
3. 4/106RR
14/M60 MG
5/3.5 RL
4/81 MM MT
4. 14/M51
6/M106A1
14/M100
6/TD 24 W/PCU
8/MRS 200
8/SCRAPER 18 CY
5/MOTOR GRADER
5. NONE
6. 1/ASPHALT PLANT
7. 11351 SQ. FT.

Changes to this report will be submitted using the reporting by exception principle, reporting only those items that change or are originally reported in error.

Loading reports submitted during an exercise must contain the exercise code name at the beginning and the end of the text and must be classified according to the content of the information submitted.

EMBARKATION/MOCC RECORDS AND FILES

An MOCC is established within each unit to coordinate the movements of the battalion during the embarkation phase.

Within the embarkation office, the unit maintains as a minimum the following files.

1. Packing lists for all company/departmental and battalion gear required for or taken on an actual mount-out. (These lists should be in sufficient detail to enable personnel to rapidly identify the contents of the box and the company/department to which it belongs. The packing list may be in the form of the unit cargo manifest, if desired.)

2. A current unit personnel and tonnage table with all supporting unit cargo manifests or packing lists.

3. A current weapons summary listing all weapons currently assigned.

4. A current personnel, supplies, and equipment report with appropriate notations to show the current status of the equipment to embark. (These forms encompass all vehicles and supplies assigned. If the unit is deployed to the Pacific area, or to the Atlantic area, these forms should show the vehicles assigned at the location. If the unit is deployed at the home port, one form is required for a full battalion allowance of equipment.)

5. Template files will be prepared for each vehicle in the P-25 allowance. (When the unit is deployed in the Atlantic Command (LANTCOM) or the Pacific Command (PACOM), the vehicle registration numbers will be added for the equipment assigned. Other data to be filled in on the card is specified in chapter 3 of *COMCBPAC/COMCBLANT Tactical Embarkation Manual*.)

6. Each unit will maintain a training file of ship's loading characteristics pamphlets (SLCPs). (COMCBLANT or COMCBPAC will supply a representative set of SLCPs to each new battalion. Also, each battalion holding an Atlantic or a

Pacific Fleet contingency designation will be issued additional SLCPs for training and review purposes. These SLCPs will be used to train embarkation personnel in the drafting of load plans, and will be maintained within the embarkation office. COMCBLANT or COMCBPAC will forward changes to SLCPs as they become available.)

PROJECT TURNOVER

About 2 weeks before an NMCB completes its deployment, the advance party of the relieving battalion is sent to the deployment site to arrange for the arrival of the main body of the battalion and to turn over projects, material, and equipment. As a member of the advance party, you will participate in the onsite proceedings which consist of taking inventory of the camp, supplies, material, and equipment to determine shortages or surpluses.

The inventories of camp, supplies, and material are conducted by members of both battalions. The items inventoried include administrative and operational machines and consumables, weapons and infantry equipment, toolkits and toolroom supplies, special clothing and bedding, NBC defensive devices, equipment and materials for communications, medical and dental services supplies and equipment, damage control and safety material, photography and barber supplies, camp facility collateral equipment and supplies, galley and messing equipment, provisions, and camp support-related equipment.

The equipment inventory, better known as the battalion equipment evaluation program (BEEP), is conducted by assigned personnel of ALFA company representing both battalions. It is a uniform procedure for evaluating and accounting for all equipment, attachments, collateral equipment, maintenance records, and correspondence.

Your part in a deployment and project turnover is important. It is best to learn, or find out as much as you can, about your projects. You must get information about the status of the projects and project materials required. Find out whether all materials have been received by supply. If so, are they at the project site or in the Material Liaison Office (MLO) yard?

You must have all the information that relates to the amount of work in place. This includes materials expended as well as man-hours. Obtain all updated drawings and specifications for the project, including as-built drawings. Also, find out whether there are problems to solve. If so, what has to be done to solve them?

Make as many contacts as you can with persons who are not attached directly to the battalion; for example, public works shop leaders and supply personnel. Remember, those you are relieving may have had a good working relationship with others who can help you in turning over the project.

You should remember that the relieving process is a very busy time with many details to cover. It is important that you determine as early as possible the role that you are to play and become as familiar as you can with your area of responsibility. In this way, both you and your counterpart will get the most out of the limited time available to complete your tasks.

In the event of mount-out for contingency operations, the project turnover may not be to a battalion. Higher authority such as the Naval Construction Regiment (NCR) and public works designates custodial responsibility for equipment and project materials.

CHAPTER REFERENCES

Category Codes for Classifying Real Property of the Navy, NAVFAC P-72, Naval Facilities Engineering Command, Alexandria, Va. 22332, March 1980.

Facilities Planning Guide, NAVFAC P-437, Volume II, Naval Facilities Engineering Command, Alexandria, Va. 22332, October 1980.

Tactical Embarkation Manual, CBLANT/CBPAC Instruction 3120.1, March 1983, Department of the Navy, Commander Naval Construction Battalions Pacific Fleet, Pearl Harbor, Hawaii 96860 and Commander Naval Construction Battalions Atlantic Fleet, Naval Amphibious Base, Little Creek, Norfolk, Va. 23521.

CHAPTER 7

PLANNING PLUMBING PROJECTS

Learning Objective: To analyze plans, specifications, and taskings used in developing and supervising projects involving plumbing installations.

As a UT1 or UTC, you will be responsible for planning the needs of plumbing projects. Chapter 5 of this manual discussed the general considerations of planning, estimating, and scheduling projects. This chapter will discuss the special considerations you will encounter when planning plumbing installations.

RESPONSIBILITIES

In today's Naval Construction Force, you will find the Utilitiesman more involved with the planning and scheduling of projects than in the past. You may be the technical advisor during both the planning and execution of a project. You will also find yourself supervising crews in the field, where you will be held responsible for following a schedule that resulted from the planning of the project. Remember, *ALL THE PLANNING IN THE WORLD IS NOT WORTH THE PAPER IT'S WRITTEN ON UNLESS PROPERLY EXECUTED IN THE FIELD.*

TECHNICAL ADVISOR

As an expert in your field, your company, operations department, and crew will expect you to have the answers to their questions about plumbing (mechanical) jobs. Your having ready access to job plans and specifications as well as plumbing codes, technical references, and manufacturers' manuals will be important in providing the answers to their questions. You are not expected to have a complete knowledge of every detail of your rating. You can be an effective technical advisor by knowing where to get answers to questions. Use your resources.

Many problems will require you to make a judgment decision based on personal experience. Do not rely on rate training manuals and A schools to provide you with everything you need to know to be a Utilitiesman. The extra effort of self-study combined with on-the-job training and field experience will enable you to make recommendations with confidence.

PLANNER

Now that you are advising people on the technical aspects of installing and maintaining plumbing systems, you may become involved in the planning of these tasks.

Planning takes on many applications and phases. Chapter 5 covers the preconstruction planning used today and how to keep the plan up-to-date during construction. This homeport planning results in a schedule that you will use in considering how and when your work is going to be done. The resulting precedence diagram along with other available information about a project will help you in managing and supervising your project.

SUPERVISOR

Your company will follow the construction schedule that was prepared during the homeport period. After your arrival at the deployment site, you may need to make changes to the schedule to show actual conditions on the job such as changes in personnel, equipment availability, or material delays. Being flexible is the most important thing to remember about a schedule. The schedule is designed to be a management tool that aids the supervisor. Used in this manner, it will alert you to problems and job requirements in enough time to eliminate delays in the project.

It is your responsibility to coordinate your requirements with other companies and departments. For example, determine material, equipment, and personnel requirements about 30 days in advance at the company level, 2 weeks in advance at the job supervisor level, and no less than 1 week in advance at the crew level. This will give supporting elements of the organization the necessary time to break out, deliver, and provide support to your job. The project you are working on will determine how much lead time planning you should allow.

During homeport planning it is not always easy to know the actual conditions on a construction site. After being on the site a while, you may want to reevaluate the original schedule. It is generally accepted that, within 45 days of the crews' arriving on the job, changes can be made to the schedule. It is during this period that you will see whether your crews will be able to finish all tasks as scheduled. It is possible that you did not allow enough time for the job or you may have overestimated it.

Good supervision should consider all required needs for the project. Coordination of the supporting elements of the construction or maintenance effort is essential. You must have equipment, material, tools, and other facilities on the job when they are needed. A missing item usually requires an extra trip back to camp, decreasing your credibility as a supervisor and affecting crew production and morale.

You put a lot of effort into your schedule. Supervision is the prime mover of that schedule. Job delays, rework, and unsafe working conditions will result without proper supervision of the schedule.

PLANNING, ESTIMATING, AND SIZING PLUMBING SYSTEMS

The planning, estimating, and sizing of plumbing systems includes sanitary, storm drainage, and water supply systems. As a UT1 or UTC, you will provide input to the construction or maintenance of these systems. This input can be in the form of installation techniques, types of material required, quantity and size of piping or fittings, and so forth. This section provides some general considerations you must take into account when you plan and estimate a plumbing system. The *National Standard Plumbing Code*, military specifications, and job specifications provide more concise information.

SANITARY SYSTEMS

Sanitary drainage systems are built of various types of pipe and fittings. Cast iron and galvanized steel are the pipe materials most often used. However, the materials that may be permitted will depend upon the location where they are to be installed (for instance, above the ground within buildings, under the ground within buildings, or under the ground outside buildings).

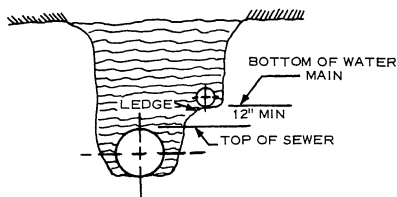
Aboveground piping within buildings consists of one or a combination of brass or copper pipe, copper tubing, extra heavy or service weight cast iron, galvanized wrought iron, galvanized steel, or lead. In single- or two-family dwellings, plastic pipe is acceptable for aboveground use.

Underground piping within buildings should be of cast iron. Service weight is used for buildings four stories and under. Extra heavy weight is required for buildings over four stories. The proper authority, however, may permit the use of other piping, such as galvanized steel, lead, or copper. Where threaded joints are used underground, they should be coated with coal tar and wrapped when installed.

Underground piping outside of buildings should be installed in a separate trench from the water-service pipe. The following materials may be used: vitrified clay, cast iron, plastic, concrete, asbestos cement, or bituminized fiber. The underground water-service and the building drain or building sewer should not be less than 6 feet apart horizontally and should be separated by undisturbed or compacted earth. Where separate systems of sanitary drainage and storm building drains are installed, they may be laid side by side in one trench. A building sewer or building drain installed in fill or unstable ground should be of cast-iron pipe, except that nonmetallic drains may be used if laid on an approved continuous supporting system. Existing building sewers and drains may be used in connection with new buildings' sewer and drainage systems only if they meet the requirements of the new systems. All joints should be watertight to prevent leakage of sewer water into the ground and infiltration of subsurface water into the sewer system. Special attention should be given the joints to prevent roots from growing into the sewer piping. The depth of the piping should be enough to protect the sewer from freezing. Also, the lines must be protected from traffic. It may be necessary to provide special protection, such as encasing the piping in concrete, where the traffic loads are heavy.

It may be necessary, at times, to install the building sewer and the water-service pipe in the same trench. (See fig. 7-1.) If so, make sure the following precautions are observed.

1. See that the bottom of the water pipe is at least 12 inches above the top of the building sewer.
2. Place the water pipe on a solid shelf at the side of the trench.



87.25

Figure 7-1.—Building sewer and water-service line in same trench.

3. Use hot-poured lead in making joints in cast-iron pipe for the building sewer; use a hot-poured compound in joining bell-and-spigot clay or concrete sewer pipe.

4. After installation, test the building sewer with not less than a 10-foot head of water, or an equivalent test.

Grading

Horizontal piping in the sanitary drainage system should be installed at a uniform slope. This slope, pitch, grade, or drop per foot will determine the flow velocity of the liquid within the pipe. Piping of 3 inches or less in diameter requires a slope of not less than 1/4 inch per foot. In house or building plumbing, pipe larger than 3 inches in diameter requires a slope of not less than 1/8 inch per foot. This allows a velocity of not less than 2 feet per second, which will provide the scouring action necessary to keep a pipe free from fouling. Sewer mains may have slopes of less than 1/8 inch per foot, providing that a cleaning velocity of 2 feet per second or greater is obtained. (See table 7-1.)

Table 7-1.—Approximate Discharge Rates and Velocities in Sloping Drains

Actual inside diameter of pipe (inches)	1/16-in./ft slope		1/8-in./ft slope		1/4-in./ft slope		1/2-in./ft slope	
	Discharge gpm ³	Velocity fps ⁴	Discharge gpm	Velocity fps	Discharge gpm	Velocity fps	Discharge gpm	Velocity fps
1 1/4							3.40	1.78
1 3/8							4.44	1.90
1 1/2					3.13	1.34	5.53	2.01
1 5/8					4.81	1.50	6.80	2.12
2					8.42	1.72	11.9	2.43
2 1/2					15.3	1.99	21.6	2.82
3			10.8	1.41	24.8	2.25	35.1	3.19
4	26.7	1.36	37.8	1.93	53.4	2.73	75.5	3.86
5	48.3	1.58	68.3	2.23	96.6	3.16	137.0	4.47
6	78.5	1.78	111.0	2.52	157.0	3.57	222.0	5.04
8	170.0	2.17	240.0	3.07	340.0	4.34	480.0	6.13
10	308.0	2.52	436.0	3.56	616.0	5.04	872.0	7.12
12	500.0	2.83	707.0	4.01	999.0	5.67	1413.0	8.02

¹ Flowing Half Full, half full means filled to a depth equal to one-half of the inside diameter.

² Discharge Rate and Velocity, computed from the Manning Formula for 1/2-full pipe, $n = 0.015$

For 1/4 full: multiply discharge by .274
multiply velocity by .701

For full: multiply discharge by 2.00
multiply velocity by 1.00

For 3/4 full: multiply discharge by 1.82
multiply velocity by 1.13

For smoother pipe: multiply discharge and velocity by 0.015 and divide by "n" value of smoother pipe.

³ Gallons per minute.

⁴ Feet per second.

Higher velocities, or greater drop per foot, will increase the carrying capacity of a drain. When designing fixture branches, keep in mind that a slope/drop of more than 1/4 inch per foot may cause siphonage of the trap seal.

Sizing Building Drains

The building drain in a sanitary system must be of sufficient size to carry off all the water and waste materials that may be discharged into it at any one time. The minimum allowable size is 3 inches for cast-iron pipe, but sound practice prescribes a 4-inch pipe, and most plumbing codes or ordinances require 4-inch pipe as a minimum. Increasing the size beyond that computed as required (the minimum of 3 inches still applies) does not increase the efficiency of the drain. The passage of liquid and solid waste through a horizontal pipe creates a natural scouring action, which is partially lost when the size of the drain is increased above the necessary size. The flow in too large a pipe is shallow and slow, and solids tend to settle to the bottom. The solids may accumulate to such an extent that they cause stoppages in the line. The optimum size of pipe should flow half full under normal use. This will create an efficient natural scouring action and still allow capacity for peak loads.

The standard method used in determining the size of a building drain is the Unit System. Drainage fixture unit system values for standard plumbing fixtures have been established and some of the most common are shown in table 7-2. Use the trap size listing at the bottom of table 7-2 for estimating drainage fixture unit (d.f.u.) values for fixtures that are not listed.

To select the correct size of pipe for a horizontal sanitary drainage system, you must first calculate the total volume of liquid waste, expressed in drainage fixture units, that the system will be subjected to. Assume, for example, that a plumbing installation is to consist of 20 water closets, valve-operated; 22 lavatories with 1 1/4-inch traps; 15 shower heads in group showers; 20 wall urinals; 2 service sinks with standard traps; and 4 floor drains (2-inch). The total discharge,

Table 7-2.—Drainage Fixture Unit Values for Various Plumbing Fixtures

Type of Fixture or Group of Fixtures	Drainage Fixture Unit Values
Automatic clothes washer (2" standpipe)	3
Bathroom group consisting of a water closet, lavatory and bathtub or shower stall:	
Flushometer valve closet	8
Tank-type closet	6
Bathtub (with or without overhead shower) 1 1/2" trap	2
Bidet 1 1/2" trap	3
Clinic sink	6
Combination sink-and-tray with food waste grinder 1 1/2" trap	4
Combination sink-and-tray with one 1 1/2" trap	2
Combination sink-and-tray with separate 1 1/2" traps	3
Dental unit or cuspidor	1
Dental lavatory	1
Drinking fountain	1/2
Dishwasher, domestic	2
Floor drains with 2" waste	3
Kitchen sink, domestic, with one 1 1/2" trap	2
Kitchen sink, domestic, with food waste grinder	2
Lavatory with 1 1/4" waste	1
Laundry tray (1 or 2 compartments)	2
Shower stall, domestic 2" trap	2
Showers (group) per head	2
Sinks:	
Surgeon's	3
Flushing rim (with valve)	6
Service (trap standard)	3
Service (P trap)	2
Pot, scullery, etc.	4
Urinal, pedestal, siphon jet blowout	6
Urinal, stall lip	4
Urinal stall, washout	4
Urinal trough (each 6-foot section)	2
Wash sink (circular or multiple) each set of faucets	2
Water closet, tank-operated	4
Water closet, valve-operated	6
Fixtures not listed above:	
Trap Size 1 1/4" or less	1
Trap Size 1 1/2"	2
Trap Size 2"	3
Trap Size 2 1/2"	4
Trap Size 3"	5
Trap Size 4"	6

expressed in drainage fixture units, would be calculated as follows from table 7-2.

Number and Type of Fixtures	Unit Values	Total Discharge
20 water closets (flush valve)	6	120
22 lavatories (1 1/4-inch traps)	1	22
15 shower heads	2	30
20 urinals (wall)	4	80
2 sinks (service)	3	6
4 floor drains (2-inch)	3	<u>12</u>
		270 d.f.u.

After calculating the total discharge and determining the slope of the piping and the velocity of flow, select the correct size of pipe by using table 7-3. Assume that the cast-iron house drain to be installed will have a slope of 1/4 inch per foot. From table 7-3, the minimum size pipe for the horizontal sanitary drainage system under discussion is 5 inches.

Table 7-3 is for cast-iron soil pipe or galvanized steel pipe house drains, house sewers, and waste and soil branches. When copper tubing is used, it may be one size smaller than shown in the table. Note that the size of building drainage lines must never decrease in the direction of flow.

When provision is made for the future installation of fixtures, those provided for must be considered in determining the required sizes of drainpipes. Construction to provide for such future installation should have a plugged fitting or fittings at the stack to eliminate any dead ends.

Sizing Stacks and Branches

The term *stack* is used for the vertical line of soil or waste piping into which the soil or waste branches carry the discharge from fixtures to the house drain. A *waste stack* carries liquid wastes that do not contain human excrement; a *soil stack* carries liquid wastes that do.

Most buildings do not have separate soil and waste stacks. A single stack known as the soil and waste stack, or simply the soil stack, serves to carry both soil and waste material. Soil stacks are usually made of cast-iron pipe with caulked joints. They may, however, be made of other materials

Table 7-3.—Maximum Loads for Horizontal Drains

Diameter of Drain	Horizontal Fixture Branch	Building Drain or Building Sewer			
		Slope			
		1/16-in/ft	1/8-in/ft	1/4-in/ft	1/2-in/ft
(inches)	(d.f.u.) ¹	(d.f.u.)	(d.f.u.)	(d.f.u.)	(d.f.u.)
1 1/4	1				
1 1/2	3				
2	6				26
2 1/2	12			24	31
3	32 ²		36 ³	42 ²	50 ²
4	160		180	216	250
5	360		390	480	575
6	620		700	840	1000
8	1400	1400	1600	1920	2300
10	2500	2500	2900	3500	4200
12	3900	3900	4600	5600	6700
15	7000	7000	8300	10000	12000

¹Drainage fixture unit.

²Not more than two water closets or two bathroom groups.

³Less than 2 feet per second.

such as galvanized steel or copper tubing. Branches are usually either threaded galvanized steel pipe with drainage (recessed) fittings or copper tubing.

Sizing the Stack

The stack is sized in the same way as the building sewer. The maximum discharge of the plumbing installation is calculated in drainage fixture units. This figure is applied to table 7-4 or table 7-5 to obtain the proper stack size.

Continuing our example, the 270 drainage fixture units would require a 5-inch stack, if the stack had less than three branch intervals. (No soil or waste stack should be smaller than the largest horizontal branch connected, except that a 4 × 3 water closet connection should not be considered as a reduction in pipe size.)

Offsets on Drainage Piping

An offset above the highest horizontal branch is an offset in the stack vent and should be considered only as it affects the developed length of the vent.

An offset in a vertical stack with a change in direction of 45 degrees or less from the vertical

piping may be sized as a straight vertical stack. In piping where a horizontal branch connects to the stack within 2 feet above or below the offset, a relief vent should be installed.

A stack with an offset of more than 45 degrees from the vertical should be sized as follows:

1. The portion of the stack above the offset should be sized for a regular stack, based on the total number of drainage fixture units above the offset.
2. The offset should be sized as for the building drain. See table 7-3.
3. The portion of the stack below the offset should be sized as for the offset, or based on the total number of drainage fixture units of the entire stack, whichever is larger. A relief vent should be installed for the offset. Never connect a horizontal branch or fixture to the stack within 2 feet above or below the offset.

Sizing Individual Waste Lines

The water closet, strictly speaking, has no waste. It is usually connected directly into the stack on a short as possible separate branch of its own by the use of a closet bend. The closet bend is 3 or 4 inches in diameter if made of cast iron or steel and 3 inches if made of copper.

Because lavatories are used for washing hair, loose hair is often carried down into the waste pipe, causing a stoppage. Lavatory drainage is improved by using a minimum number of fittings and by eliminating long horizontal runs. The minimum pipe size for lavatory wastes is 1 1/4 inches, but 1 1/2 inches is more satisfactory.

Urinals present a particular problem because cigarette butts, cigar stubs, chewing gum, matches, and so on are often discarded in them. These materials can easily cause a stoppage. For this reason, urinals should be equipped with an effective strainer. Size of waste pipe should be at least 1 1/2 inches for wall-mounted urinals and 3 inches for the pedestal siphon jet urinal.

Shower wastes seldom cause trouble since they have a relatively clear water waste flowing through them. The usual diameter of the waste pipe for a single shower is 2 inches if made of cast iron or steel and 1 1/2 inches if made of copper.

A domestic kitchen sink requires a 1 1/2-inch cast-iron or steel waste pipe. When a sink is equipped with a garbage disposal unit, a minimum of 2 inches is required for the cast-iron or steel drainage piping.

Table 7-4.—Maximum Loads for Soil and Waste Stacks Having Not More Than Three Branch Intervals

Diameter of Stack (inches)	Maximum Load	
	On Any One Branch Interval	On Stack
	(d.f.u.) ¹	(d.f.u.)
1 1/4	1	2
1 1/2	2	4
2	4	9
2 1/2	8	18
3	20 ²	48 ²
4	100	240
5	225	540
6	385	930
8	875	2100

¹Drainage fixture unit.

²Not more than two water closets or bathroom groups within each branch interval nor more than six water closets or bathroom groups on the stack.

Table 7-5.—Maximum Loads for Soil and Waste Stacks Having Four or More Branch Intervals

Diameter of stack (inches)	Number of Branch Intervals									
	4	5	6	7	8	9	10	11	12	13
in.	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval
2	d.f.u. ¹	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.
3a	13	3	16	18c	170	1,360	1,400c	280	2,800	3,500
4	18a	72a	85a	96a	102ac	1,215	1,400c	280	2,800	3,500
5	90	360	84	420	80	480	530c	640	5,780	11,250
6	205	820	190	950	180	1,080	1,75	2,320	285	1,125
8	350	1,400	325	1,625	310	1,860	299	4,725	655	1,145
10	785	3,140	735	3,675	700	4,200	675	8,435	1,170	1,825
12	1,405	5,620	1,310	6,550	1,200	7,500	1,205	13,160	1,880	23,620
15	2,195	8,780	2,045	10,225	1,950	11,700	1,880	23,620	3,210	28,880
	3,935	15,740	3,675	18,375	3,500	21,000	3,375	26,240	3,150	31,500

Number of Branch Intervals

Diameter of stack (inches)	Number of Branch Intervals									
	11	12	13	14	15	16	17	18	19	20
in.	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval	on any one interval
2	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.
3a	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.
4	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.
5	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.	d.f.u.
6	265b	2,900c	585b	7,600c	14,070	21,960	35,390	42,015	24,800	1,620b
8	620	6,830	1,080	14,070	21,960	35,390	42,015	24,800	1,620b	26,000c
10	1,110	12,200	1,095	13,100	21,960	35,390	42,015	24,800	1,620b	26,000c
12	1,730	19,020	1,705	20,500	21,960	35,390	42,015	24,800	1,620b	26,000c
15	3,100	34,160	3,060	36,700	3,030	39,390	42,015	24,800	1,620b	26,000c

¹ Drainage fixture units.

a. Not more than two water closets or bathroom groups within any one branch interval and not more than six water closets or bathroom groups on the stack.

b. Loads on any one branch interval for higher stacks shall not exceed these values; however, this shall not prevent the installation of higher stacks.

c. Stack loads for higher stacks shall not exceed these values; however, this shall not prevent the installation of higher stacks.

There are two styles of service sinks (slop sinks): the trap-to-wall and the trap-to-floor. They are used for disposal of wash water, filling swab buckets, and washing out swabs. The trap-to-wall type requires a 2-inch or 3-inch waste pipe; the trap-to-floor, a 3-inch waste pipe. For both types, if copper tubing is used, a one size reduction is allowed.

Scullery sinks are large sheet metal sinks used for washing large pots and pans and for general scouring purposes. The large amount of grease that usually passes through a scullery sink makes a 2-inch waste pipe necessary.

Drinking fountains carry only clear water wastes and a 1 1/4-inch waste pipe is suitable. An indirect drain (covered later in this chapter) should be used.

Sizing Sanitary Collecting Sewers

The design and sizing of collecting sewers, the subtrunks, and the main trunk lines are provided by engineers. However, the UT should understand the factors that contribute to the design and the requirements that must be met.

While the unit system is used to size the building sanitary piping and the building drain, the sewage quantities used in sewer design normally are computed on a contributing population basis. The population to be used in design depends upon the type of area that the sewer is to serve. If the area is strictly residential, the design population is based on full occupancy of all quarters served. If the area is industrial, the design population is the greatest number employed in the area at any time. There are exceptions to the general rule that sewers must be designed on a population basis. Among these exceptions are laundry sewers and industrial-waste sewers. The per capita contribution for sewer design varies. Typical values are 100 gallons per person per day for permanent residents and 30 gallons per person in the industrial area per 8-hour period.

The sizing of the sewer includes the average rate and the extreme (peak) rate of flow (which occurs occasionally). The ratio of the peak rate of flow to the average rate of flow may vary with the area served, because the larger the area or the greater the number of persons served, the greater the tendency for flow to average out. Typical peak flows might range from 6 for small areas down to 1.5 for larger areas.

An allowance for infiltration of subsurface water is added to the peak flow to obtain the

design flow. A typical infiltration allowance is 500 gallons per inch of pipe diameter, per mile of sewer per day.

Additional capacity to provide for population increase is usually included for areas that are likely to continue to develop. Provision of approximately 25 percent additional capacity over the initial requirements is advisable.

Each length of pipe from one manhole to the next is sized to carry the design flow. However, to help prevent clogging and to facilitate maintenance, a minimum size is usually specified which may be larger than is necessary to carry the design flow at the upper ends of the system. Typical minimum sizes are 6-inch pipe for house and industrial-waste sewers and 8-inch pipe for all other sewers.

It is sometimes the practice to select a pipe size that will carry the design flow when the pipe is half full, thus allowing for expansion. More often, however, sufficient safety factors in the future population estimate and the peak flow factor are included so the pipe may be designed to carry the design flow when flowing full.

The formulas or tables used in sizing the pipe are based on experiments and experience. One of the factors taken into account is the roughness of the pipe. Asbestos-cement pipe, for example, is smoother than concrete pipe. Because there is less friction on the inside of the asbestos-cement pipe, it will carry a greater flow than concrete pipe of the same size.

Another factor is the slope at which the pipe will be laid. The slope will generally be determined by the fall available on the natural ground area through which the sewer runs. The plans for collecting sewer systems generally show slope (or grade) in terms of fall per hundred feet. Slope is sometimes expressed as a percent rather than in inches per foot. A 1 percent slope means 1 foot of fall in a 100-foot length of pipe, or about 1/8 inch per foot. A 0.5 percent slope (6 inches in 100 feet) is about 1/16 inch per foot.

Table 7-6 gives the minimum slope for some of the most commonly used pipe sizes. The slope should remain constant in the section between each manhole. Each section between successive manholes should be analyzed and the slope for that particular section determined. If the fall is relatively steep, the velocity of the flow is faster and a smaller pipe size may be used. If the slope is relatively flat, the velocity is slower and a larger pipe size may be used. In the larger pipe, the depth of flow may decrease to such extent that the velocity might be no greater than a smaller pipe

Table 7-6.—Minimum Slope for Sewer Pipe

Inside pipe diameter (inches)	Minimum fall (ft per 100 ft)
6	0.6
8	0.4
10	0.3
12	0.24
18	0.14

on the same grade. Therefore, an increase in pipe size to obtain the desired flow velocity is limited by the rate of flow. Typical minimum flow velocities are 2 feet per second when the design flow fills the pipe and 1.6 feet per second at the average rate of flow. Maximum velocities must also be considered; too high a velocity will erode the pipe. A typical maximum velocity is 15 feet per second for concrete pipe. Because of the differences in available slopes, smaller pipe may be used in some sections than is required in an upper section of the same sewer. The pipe size should be reduced whenever better flow conditions would result.

Manholes provide access to sewers for inspection and cleaning. They are placed where there is a change in grade, a change in pipe size, a junction of two or more sewerlines, or a change in direction. Otherwise, they are placed at intervals of 300 or 500 feet of sewerline. The manholes should be built so there is no decrease in velocity and a minimum of water disturbance. The channel should be deep enough to prevent sewage from spreading over the manhole bottom. The covers should be of a weight strong enough to support the expected traffic. Perforated covers should not be used for sanitary sewer manholes, because openings in the sewer manhole would permit the entrance of sand, grit, and surface water. The sewers are ventilated by the stacks of the building plumbing systems.

STORM DRAINAGE SYSTEMS

Storm drainage systems are designed to drain all surface and sometimes subsurface water that may cause damage to Navy facilities, property, or adjoining land. They consist of pipe, inlets, catch basins, and other drainage structures to carry the surface runoff and subsurface water to a point of disposal.

Storm drainage systems should be separate from sanitary sewage systems wherever possible. Some Navy bases may have combination systems still in use. However, storm water should never be drained into sewers intended for sanitary sewage only.

EOs and BUs generally are responsible for building ditches, culverts, and other structures that are a part of storm sewers. Therefore, construction of these facilities is not covered in this chapter.

The UT is generally concerned with only the pipework itself. This involves laying storm drain lines both inside and outside buildings and other structures. This pipe material may be the same as that used for the sanitary system. Storm sewer systems, however, may include pipe of much larger sizes than are needed for sanitary sewers. Plain or reinforced concrete pipe (rather than clay, cast iron, or asbestos cement) is generally used for the larger lines. Also, it is not so important that the joints be watertight in storm sewer systems. In fact, the mortar is sometimes omitted from a portion of the joint and washed gravel is placed next to the opening; the storm drain thus serves also as an underdrain to pick up subsurface water.

Installation Considerations

Storm and sanitary systems may differ in the installation of the piping. Building storm drains should generally be graded at least 1/4 inch per foot whenever feasible. This amount of drop per foot provides an unobstructed and self-scouring flow. However, a greater drop per foot may be given as no fixture traps which might lose their seals are associated with it.

When a change of direction is necessary, long radius fittings are used and a cleanout need not be installed. This is especially true in and under buildings. But a manhole is used outside of buildings when a change of direction is necessary, or when two or more lines are connected together.

Sizing Building Storm Drains

To determine the size of building storm drains, a number of factors must be considered, such as rainfall intensity, roof size, and pitch of roof. Tables have been made for use in estimating the

size of pipe to select. One example is table 7-7; it shows storm drain sizes. Remember that this table is to be used only as a guide when estimating for storm drainage, as different areas have different intensities of rainstorms.

Another method for sizing building storm drains is to provide 1 square inch of pipe cross-sectional area for each 100 square feet of roof area. This method is easy to remember: 1 square inch for 100 square feet. (However, it is not as accurate as using table 7-7.) Using this method, you can prepare a table similar to table 7-8. Show the diameter in the first column; then the radius (which is one-half the diameter); then the square of the radius; then the cross-sectional area, which is π (3.14) times the radius squared. Since each square inch may take 100 square feet of roof, move the decimal of the square inches over two places to the left (which is multiplying by 100) to get the area of the roof that may be drained to the pipe. As you can see by comparing table 7-7 with table 7-8, the second method is much more conservative.

Sizing Site Storm Sewers

While rules of thumb such as those just described are used to size building storm drains, different procedures are used to size the storm sewers that carry the runoff from the building site and surrounding land areas. The design and

sizing of storm drains are provided by engineers. It is not necessary that the UT understand the factors that contribute to the design. Therefore, the information is not included here.

WATER SUPPLY SYSTEMS

After the pipe runs and fittings are located on a print or drawing, the size, quantity, and joining requirements of the pipe must be determined. When a plumbing print is available for the job, it will contain this information. If there is no blueprint, you must determine these requirements yourself. The quantity of pipe required and the number and types of fittings you intend to use

Table 7-8.—Fixture Demand

Fixture	Units ^a	Gallons per minute
Water closet	6	45
Urinal	5	39 1/2
Slop sink	3	22 1/2
Shower	2	15
Laundry tray	2	15
Bathtub	2	15
Kitchen sink	2	15
Lavatory	1	7 1/2

^a1 unit = 7 1/2 gallons per minute

Table 7-7.—Size of Horizontal Building Storm Drains and Building Storm Sewers

Diameter of Drain (inches)	Maximum Projected Area for Drains of Various Slopes					
	1/8-Inch Slope		1/4-Inch Slope		1/2-Inch Slope	
	Square Feet	gpm ²	Square Feet	gpm	Square Feet	gpm
3	822	34	1,160	48	1,644	68
4	1,880	78	2,650	110	3,760	156
5	3,340	139	4,720	196	6,680	278
6	5,350	222	7,550	314	10,700	445
8	11,500	478	16,300	677	23,000	956
10	20,700	860	29,200	1,214	41,400	1,721
12	33,300	1,384	47,000	1,953	66,600	2,768
15	59,500	2,473	84,000	3,491	119,000	4,946

¹ Table 7-7 is based upon a maximum rate of rainfall of 4 inches per hour for a 5 minute duration and a 10 year return period.

Where maximum rates are more or less than 4 inches per hour, the figures for drainage area shall be adjusted by multiplying by four and dividing by the local rate in inches per hour.

²Gallons per minute.

are easily determined by tracing the layout of the water supply system as drawn in a print or sketch. Determining the size pipe you will require to meet the fixture demand of a facility is more complicated and will be discussed in this section.

Sizing Cold-Water Supply Systems

Some factors that affect the size of the water service in a plumbing system are the types of flush device used on the fixtures, the pressure of the water supply in pounds per square inch (psi), the length of the pipe in the building, the number and kind of fixtures installed, and the number of fixtures used at any given time. The stream of water in a pipe is made up of a series of layers moving at different speeds with the center layer moving the fastest. The resistance to flow is called *pipe friction* and causes a drop in pressure of the water flowing through the pipe. Friction loss may be overcome by supplying water at greater pressure than would normally be required or by increasing the size of the pipe.

The two most important things to consider are the maximum fixture demand and the factor of simultaneous fixture use. The *maximum fixture demand* in gallons is the total amount of water that would be needed to supply all fixtures if they were being used at the same time for 1 minute. Since it is very unlikely that all fixtures would be turned on at the same time, a probable percentage of the fixtures in use at any given time must be found. This is the *factor of simultaneous use*. The more fixtures in a building, the smaller the possibility that all will be used at the same time. Therefore, simultaneous use factors decrease as the number of fixtures increase.

To estimate the maximum fixture demand in gallons, the number and type of all fixtures in the completed plumbing system must be known. Table 7-8 is used to obtain the maximum fixture demand. For example, assume a plumbing system consists of three urinals, two water closets, one slop sink, two shower stalls, one kitchen sink, one laundry tray, and four lavatories. From table 7-8 a maximum fixture demand of 321 gallons per minute (gpm) can be figured. Normally only a small percentage of fixtures would be used at the same time, so the maximum fixture demand is reduced by applying the factor of simultaneous use.

The factor of simultaneous use, also called the probable demand, is only an estimate. Table 7-9 gives data for making an estimate of probable demand. When using this table, take the actual

number of fixtures installed, not the fixture unit value. For example, five fixtures would have a probable demand of about 50 percent, while 45 fixtures would have a probable demand of about 25 percent. When a table showing the factors of simultaneous use is not available, a practical way of figuring the probable demand is 30 percent of the maximum fixture demand in gallons.

Many factors affect the flow of water through pipes resulting in a loss of water pressure. Difficult calculations are required to consider all the factors involved that may cause a loss of water pressure. These calculations are beyond the range of this manual. For simple systems, approximate figures are acceptable for most plumbing installations.

Table 7-10 (for galvanized iron pipe) and table 7-11 (for copper tubing) may be used with the maximum fixture demand and the factor of simultaneous use to find the correct size of pipe for water-service lines. The minimum practical size for a water-service line is 3/4 inch. This size should be used even when calculations show that a smaller size could be used.

To continue the example above, the 14 fixtures would have a factor of simultaneous use of about 35 percent. Since the maximum fixture demand was 321 gpm, the water-service line must have a capacity of 35 percent of 321, or 112 gpm. Assuming a length of pipe 60 feet long and a pressure at the main of 40 psi, table 7-10 or 7-11 shows that either a 1 1/2-inch galvanized iron or a 1 1/2-inch copper tubing water-service line would be large enough for the example fixture demand.

Sizing Hot-Water Supply Systems

The hot-water system is that part of the plumbing installation that heats water and distributes it to various fixtures. There are many ways of heating the water, but whichever is used must be able to supply maximum demand. The materials used in hot-water systems are similar to those used in cold-water supply systems. The use

Table 7-9.—Factors of Simultaneous Use

No. of fixtures	Percent of simultaneous use
1-4 -----	50-100
5-50 -----	25-50
51 or more -----	10-25

Table 7-10.—Capacities of Pipe in Gallons Per Minute (Galvanized Iron)

a. 3/8 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	5	3	3	2	2	2	----	----	----	----
20	9	5	4	3	3	3	2	2	2	2
30	10	6	5	4	4	3	3	3	3	2
40	----	8	6	5	4	4	4	3	3	3
50	----	9	7	6	5	4	4	3	3	3
60	----	9	7	6	6	5	5	4	4	4
70	----	10	8	7	6	6	5	5	4	4
80	----	----	8	7	7	6	5	5	5	4

b. 1/2 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	10	8	5	5	4	3	3	3	3	3
20	14	10	8	6	6	5	5	4	4	4
30	18	12	10	8	8	7	6	6	5	5
40	20	14	11	10	10	8	7	7	6	6
50	----	16	13	11	11	9	8	7	7	7
60	----	18	14	12	12	10	9	9	8	7
70	----	----	15	13	12	11	10	9	8	8
80	----	----	----	----	----	----	----	----	----	----

c. 3/4 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	22	14	12	10	8	8	7	6	6	6
20	30	22	18	14	12	12	11	10	10	8
30	38	26	22	18	16	14	13	12	12	10
40	----	30	24	21	19	17	16	16	15	13
50	----	34	28	24	21	19	18	17	16	15
60	----	38	31	26	23	21	20	19	18	17
70	----	----	34	29	25	23	22	21	19	18
80	----	----	36	30	27	24	23	22	21	20

d. 1 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	40	28	22	18	16	15	14	13	12	11
20	55	40	32	27	24	22	20	19	18	16
30	70	50	40	34	30	27	25	23	22	20
40	80	58	45	40	35	32	29	27	25	24
50	----	65	57	45	40	36	33	31	29	27
60	----	70	58	50	44	40	36	34	32	30
70	----	76	63	54	45	42	40	37	34	32
80	----	----	65	57	47	43	39	37	35	33

Table 7-10.—Capacities of Pipe in Gallons Per Minute (Galvanized Iron)—Continued

e. 1 1/4 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	80	55	45	37	35	30	27	25	26	24
20	110	80	65	55	50	45	41	38	36	34
30	----	100	80	70	60	56	51	47	45	42
40	----	----	95	80	72	65	60	56	52	50
50	----	----	107	92	82	74	68	63	60	55
60	----	----	----	102	90	81	75	70	65	62
70	----	----	----	----	97	88	82	74	69	67
80	----	----	----	----	105	95	87	79	74	72

f. 1 1/2 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	120	90	70	60	55	50	45	40	40	35
20	170	130	100	90	75	70	65	60	55	55
30	----	160	130	110	100	90	80	75	70	65
40	----	170	150	130	110	100	90	90	80	80
50	----	----	170	140	130	120	110	100	90	90
60	----	----	----	160	140	130	120	110	100	100
70	----	----	----	170	150	140	130	120	110	100
80	----	----	----	----	160	150	140	130	120	110

g. 2 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	240	160	130	110	100	90	90	80	80	70
20	300	240	200	160	150	140	130	120	110	100
30	----	300	240	200	180	160	150	140	140	130
40	----	----	280	240	220	200	180	160	160	150
50	----	----	----	280	240	220	200	200	180	160
60	----	----	----	----	280	240	220	200	200	180
70	----	----	----	----	300	260	240	220	220	200
80	----	----	----	----	----	280	260	240	220	220

Table 7-11.—Capacities of Pipe in Gallons Per Minute (Copper Tubing)

a. 1/2 inch										
Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	8	5	4	3	3	2	2	2	2	2
20	12	8	6	5	5	4	4	3	3	3
30	15	10	8	7	6	5	5	4	4	4
40	17	12	9	8	7	6	6	5	5	4
50	----	14	10	9	8	7	6	6	5	5
60	----	15	12	10	9	8	7	7	6	6
70	----	----	13	11	10	9	8	7	7	6
80	----	----	14	12	10	10	8	8	7	7

b. 5/8 inch										
Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	12	8	7	6	5	5	4	4	3	3
20	18	12	10	9	7	6	6	5	5	5
30	22	16	12	10	9	9	8	7	6	6
40	26	18	14	12	10	10	9	8	8	7
50	----	22	16	14	12	11	10	9	9	8
60	----	24	18	16	14	13	12	11	10	9
70	----	----	20	18	15	14	13	12	11	10
80	----	----	22	19	16	15	14	13	12	11

c. 3/4 inch										
Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	20	14	10	10	8	8	6	6	6	5
20	30	20	16	14	12	10	10	10	8	8
30	36	26	20	17	15	14	13	11	10	8
40	----	30	24	20	18	16	15	14	13	12
50	----	34	28	24	20	18	16	16	14	14
60	----	36	30	26	22	20	18	18	16	16
70	----	----	32	28	24	22	20	18	18	16
80	----	----	36	30	26	24	22	20	18	18

d. 1 inch										
Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	50	30	24	20	18	16	14	14	12	12
20	70	45	36	30	26	24	22	20	18	18
30	80	55	45	38	34	30	28	26	24	22
40	----	65	55	45	40	36	32	30	28	26
50	----	75	60	50	45	40	36	34	32	30
60	----	80	65	55	50	45	40	38	36	34
70	----	----	70	60	55	50	45	40	38	36
80	----	----	80	65	60	50	50	45	40	40

Table 7-11.—Capacities of Pipe in Gallons Per Minute (Copper Tubing)—Continued

e. 1 1/4 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	80	55	42	37	32	30	27	25	22	22
20	110	80	65	55	47	42	40	35	35	32
30	----	105	80	70	60	55	50	45	42	40
40	----	110	95	80	70	65	60	55	50	47
50	----	----	110	90	80	70	65	60	57	55
60	----	----	----	105	90	80	75	70	65	60
70	----	----	----	110	100	90	80	75	70	65
80	----	----	----	----	105	95	85	80	75	70

f. 1 1/2 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	130	90	70	60	50	45	40	40	35	35
20	170	130	100	90	75	70	65	60	55	50
30	----	170	130	110	100	90	80	75	70	65
40	----	----	155	130	115	105	95	88	80	77
50	----	----	170	150	130	120	108	100	90	88
60	----	----	----	165	145	130	120	110	105	98
70	----	----	----	170	160	142	130	122	113	106
80	----	----	----	----	170	155	140	130	122	115

g. 2 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	280	180	150	145	110	100	90	85	80	70
20	320	280	220	190	165	160	140	125	120	110
30	----	320	280	240	210	180	170	160	150	140
40	----	----	320	280	240	220	200	190	175	160
50	----	----	----	320	280	250	230	210	200	190
60	----	----	----	----	300	280	260	240	220	200
70	----	----	----	----	320	300	280	260	240	230
80	----	----	----	----	----	320	300	280	260	240

of copper has become the most popular because of copper's ability to resist corrosion that increases in proportion to the temperature of the water. Sizing of the piping for a hot-water system is done the same way as for a cold-water system.

The layout of a hot-water system is designed to carry heated water from a storage unit to plumbing fixtures. Installation planning begins with the water-heating device and a main supply line from that device. The system should be graded to a centrally located drip cock near the water heater to allow for draining the system when maintenance is required. Water for the individual fixtures located throughout the facility is taken off the main hot-water supply by risers as needed.

Each fixture riser should have a valve to make repair work easier.

Buildings of considerable floor area or of multifloor construction have the added problem of supplying hot water to the fixture as soon as possible after the tap is opened. In a one-pipe system (such as that used for cold-water supply), a lag occurs from the time the hot-water tap is opened until the heated water travels from the water-heating device to the fixture. To overcome this lag, a circulating water supply system is often used. (See fig. 7-2.)

The circulating supply system is a two-pipe system in which hot water flows from the heating device through the main fixture risers and returns to the heating device. This type of looped system

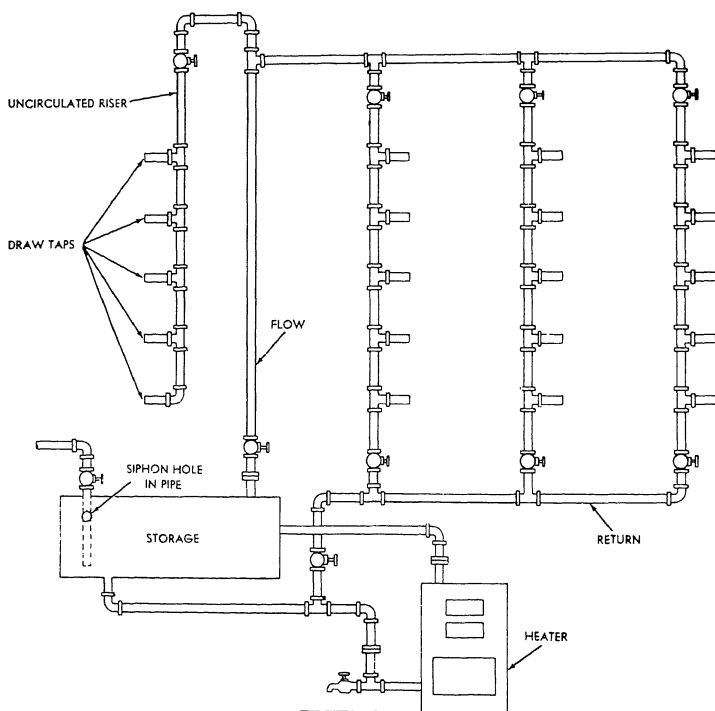


Figure 7-2.—Hot-water circulating supply system.

87.338

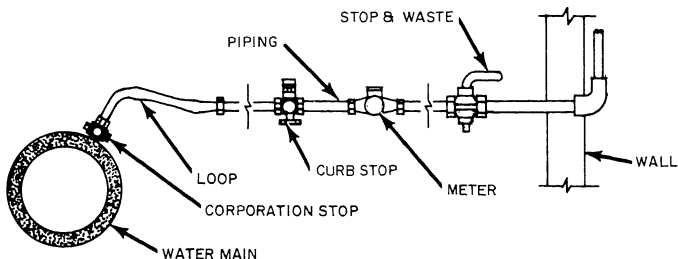


Figure 7-3.—Typical building water supply system.

87.339

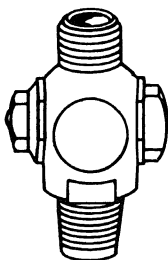


Figure 7-4.—Corporation stop.

87.340

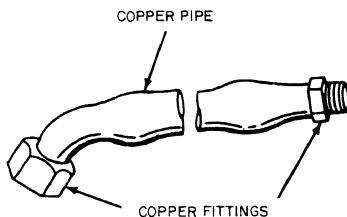


Figure 7-5.—Flexible gooseneck connector.

87.341

provides for circulation of the hot water at all times. The circulation is created because warm water tends to rise and cold water tends to fall.

The circulating system shown in figure 7-2 is known as an overhead feed and gravity-return system because of its construction. This type of system tends to become airbound, preventing circulation of the hot water. Since air collects at the highest point of the distribution piping, the most practical way to relieve the air lock is to connect an uncirculated riser to the line at that point. Any air lock that develops is relieved when a fixture on the uncirculated riser is used.

Piping and Fitting General Requirements

A typical building water-service line is shown in figure 7-3. This line is composed of a corporation stop, a flexible connector, a curb stop, a stop and waste valve, and a meter stop or gate valve.

The corporation stop is installed at the location (fig. 7-4) on the water main where a tap is made. Its function is to make the removal of the tapping machine and the installation of the remaining fittings easier by securing the water flow from the tap. A corporation stop may not be needed if you are installing building service lines from a newly installed, unpressurized water main.

When you install the line between the corporation stop and the curb stop, use some type of flexible connection for joining the pipe to the corporation stop. This flexible connection protects the corporation stop from strain or damage that can result from any movement of the water main or service pipe because of settling, earth movement, or expansion and contraction.

Several types of flexible connectors are used. The type you choose will depend on the type of material used for the supply line. A *gooseneck* (fig. 7-5) is used when galvanized iron or steel

pipe is used as the supply line. It consists of a length of copper pipe with fittings wiped or soldered on each end. Another flexible connector is the *swing joint* type commonly used with galvanized iron or steel service lines. (See fig. 7-6.) This connection consists of two elbows separated by a short section of pipe or a nipple. Next is the *expansion loop* (fig. 7-7) used when copper tubing is used as the service line.

A curb stop must be provided in every service line to conform to the *National Standard Plumbing Code*, paragraph 10.12.1. (See fig. 7-8.) The curb stop provides an accessible shutoff of the water supply to the building.

Next, a stop and waste valve (fig. 7-9) will be installed to conform to the *National Standard Plumbing Code*, paragraph 10.12.2. This valve

is used to drain the building water system. It must be installed at a point where drainage by gravity can be achieved. When the valve is turned off, drainage will occur through a drilled passage in the valve body.

Finally, a meter stop is installed when a water meter is to be included in the service line (fig. 7-10). It is installed on the pressure side of the meter and can be used for convenient securing of the water supply to the building. Where no meter is used, a simple gate valve may be provided for convenient use when repairing or maintaining the building water lines.

Each fixture to be installed requires a fixture stop valve and a certain size branch and riser piping. Branch lines are calculated in the same fashion as service supply lines. Risers for each

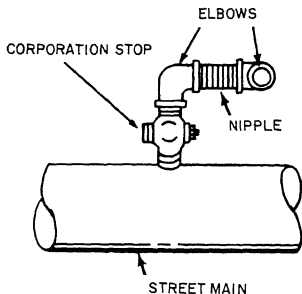


Figure 7-6.—Typical swing joint.

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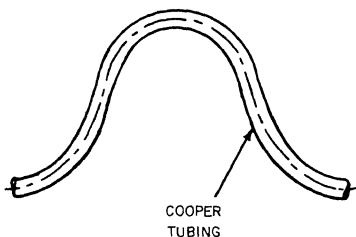


Figure 7-7.—Expansion loop.

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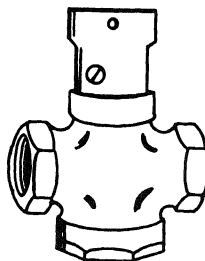


Figure 7-8.—Curb stop.

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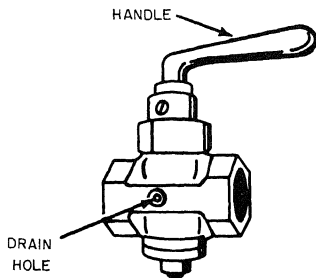


Figure 7-9.—Stop and waste valve.

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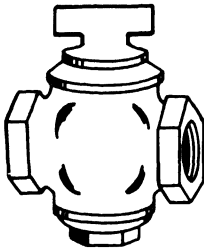


Figure 7-10.—Meter stop.

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individual fixture are sized according to table 7-12 for both cold- and hot-water risers. A typical layout for branch lines and fixture risers is shown in figure 7-11.

For more complete information, refer to the latest edition of the *National Standard Plumbing Code*. The code will guide you in determining all required installation considerations of facility water supply system needs.

CORROSION PREVENTION AND PROTECTION

As a Utilitiesman, you must consider the effects of corrosion on the equipment that you are installing. When planning a project, the

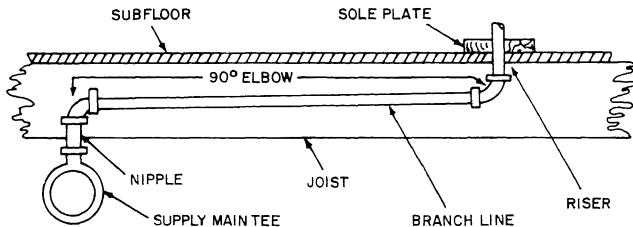


Figure 7-11.—Water supply branch line.

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Table 7-12.—Water Pipe Size Chart for Plumbing Fixtures

PLUMBING FIXTURE	PIPE DIAMETER (inches)
Dishwasher	1/2 or 3/4
Water closet tank	1/2
Water closet flushometer valve	1
Urinal with flushometer valve	1/2
Lavatory	1/2
Shower bath	1/2
Kitchen sink	1/2
Slop sink	1/2
Scullery sink	3/4
Laundry tray	1/2
Drinking fountain	1/2
Hot-water heater (domestic)	3/4
Bathtub	1/2

necessary materials and equipment required for galvanic cathodic protection of underground pipes and fittings must be considered. First you must understand what corrosion is and how it occurs.

TYPES OF CORROSION

Man has had corrosion problems to contend with ever since he started making articles out of metal. For thousands of years, the only fact known about corrosion was that it would affect some metals more than others. For example, iron, one of the most abundant and useful metals, corrodes very much; whereas metals such as gold, platinum, and silver corrode very little. Later, men began to study corrosion to find out what caused it. As might be expected, many theories were proposed to explain corrosion and its causes. Among the many theories, the electrochemical theory is most generally accepted as an explanation of corrosion.

The electrochemical theory of corrosion is best explained by the action that takes place in a galvanic cell. A galvanic cell can be produced by placing two dissimilar metals in a suitable electrolyte, as shown in figure 7-12. The resulting electrochemical reaction develops a potential difference between these metals. This causes one metal to be negative or anodic and the other metal to be positive or cathodic. In a dry cell battery, the zinc case is the anode and the carbon rod the cathode. Now, when an external electrical circuit

is completed, current flows from the zinc case into the electrolyte, taking with it particles of zinc. This is an example of galvanic corrosion of the zinc case. It is this electrochemical action that illustrates the electrochemical theory.

Corrosion may be divided into several types, such as uniform corrosion, localized corrosion, and compositional corrosion. Each type will be explained in the following paragraphs.

Uniform Corrosion

Uniform corrosion is caused by direct chemical attack. An example of this type of corrosion is zinc exposed to hydrochloric acid. If you examine the surface of zinc in a solution of hydrochloric acid, you will find that the entire surface is corroding. Furthermore, if the zinc is left in the acid long enough, it will be dissolved by the acid.

Localized Corrosion

Localized corrosion is caused by the electrolytic action of a galvanic cell. A local galvanic action is set up when there is a difference of potential between the areas on a metallic surface that is an electrolyte. Localized corrosion may be in the form of pits, pockets, or cavities due to the deterioration or destruction of metal.

Localized corrosion may develop under a number of various conditions when different types

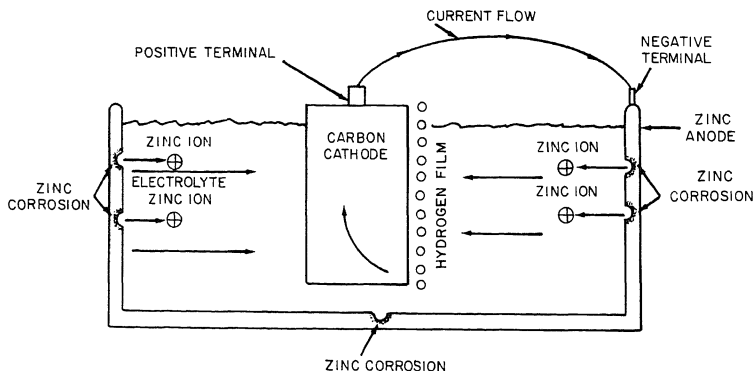


Figure 7-12.—Galvanic cell showing internal galvanic action.

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of equipment are buried in the ground. Some examples of localized corrosion are discussed in the following paragraphs.

- Corrosion due to mill scale. The mill scale embedded in the walls of iron pipe during its manufacture is one cause of pipe corrosion. It actually becomes the cathodic area, the iron pipe the anodic area, and the moist soil the electrolyte, as shown in figure 7-13. Current leaves the iron pipe wall and passes through the electrolytic soil to the mill scale. This electrochemical action causes severe pitting of the pipe metal at the anodic areas. Continued action of this type will eventually weaken the pipe to the extent of failure.

- Corrosion due to cinders. Another type of corrosion occurs when iron pipe is laid in a cinder-fill in direct contact with the cinders. The cinders and the iron pipe make up the dissimilar metals. The pipe forms the anodic area, the cinders form the cathodic area, and the highly ionized soil serves as the electrolyte. The current leaves the pipe through the soil to the cinders and returns to the pipe. Severe corrosion occurs at the points where the current leaves the pipe.

- Corrosion due to dissimilarity of pipe surface. This type of galvanic corrosion occurs when there are bright or polished surfaces on some areas of the pipe walls in contact with suitable electrolytic soil. These bright surfaces become anodic to the remaining pipe surfaces. In highly ionized soil, the polished surfaces corrode at an

accelerated rate, thus weakening the pipe at that point.

- Corrosion due to different soil conditions. This is a general corrosion problem, especially prevalent in highly alkaline areas. Corrosion currents leave the pipe wall and pass into compact soils and enter the pipe wall from light sandy soils. The intensity of the corrosion currents and the resulting rate of corrosion at the anodic areas of the pipe are directly proportional to the conductivity of the soil.

- Corrosion due to stray currents. Direct current circuits that pass in and out of an electrolyte usually cause stray currents, many of which are a direct cause of corrosion. Corrosion does not occur at the point where the current enters the structure, because it is cathodically protected. However, at the section where the current leaves the structure, severe stray current corrosion occurs. Over a period of a year, this type of corrosion has been known to displace as much as 20 pounds of pipe wall for every ampere of current.

- Corrosion due to bacteria. Biological corrosion is another distinct type of corrosion caused by electrolytic or galvanic cell action. It is the deterioration of metals by corrosion processes that occurs as either a direct or an indirect result of the metabolic activity of certain minute bacteria, particularly in water or soil environments. These organisms that cause bacterial corrosion are bacteria, slime, and fungi.

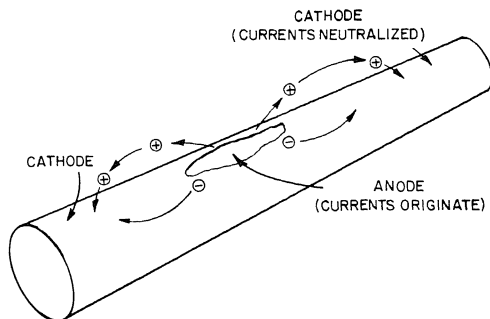


Figure 7-13.—Pipe with corroding (anode) and noncorroding (cathode) areas.

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Microbiological corrosive action in the soil is due to physical and chemical changes in the soil caused by the presence of these organisms. Some bacteria are responsible for the production of active galvanic cells. These bacteria are mostly found in highly waterlogged, sulfate-bearing, blue clay soils. The bacteria concentration, as well as the corrosion rate, varies considerably with the different seasons of the year. Cast-iron and steel pipes are corroded mostly by sulfide production.

Compositional Corrosion

Compositional corrosion alters the composition of metals. Some of the specific types of compositional corrosion are discussed in the following paragraphs.

- **Dezincification.** This is a selective type of corrosion that occurs in copper and zinc alloys. When alloys of this kind (brasses) are exposed to this type of corrosion, the zinc dissolves out of the alloy and leaves only the copper.

- **Graphitization.** Another type of compositional corrosion is graphitization or graphitic softening. It is a peculiar form of disintegration that attacks grey cast iron. Cast iron is an alloy made of iron and carbon, the carbon being in the form of graphite. When cast iron with such a composition is subjected to graphitization, the iron dissolves out and leaves only the graphite. This action leaves cast-iron pipes and other similar equipment weakened mechanically. However, after graphitization corrosion occurs, the graphite pipe may last for many years if it is not subjected to any mechanical forces or sudden pressures. The action of this type of corrosion is similar to dezincification.

- **Hydrogen embrittlement.** This is a term applied to metal that becomes brittle because of the action of some form of corrosion that causes the formation of hydrogen on its surface. When hydrogen forms on the surface of steel, the action of the hydrogen may form blisters or actually embrittle the metal. Hydrogen liberated near the surface of steel in an electrolyte will diffuse into the metal quite rapidly. The hydrogen picked up by the steel is in an atomic state and causes the steel to become brittle.

When the production of atomic hydrogen on the surface of the metal stops, the hydrogen leaves the metal in a few days and the metal again regains its original ductility.

Stress Fatigue of Metals

Corrosion affects metals that are under stress. The action caused by stresses on a pipeline or structure is due to the shifting of the various rocks and soils of the earth. Usually a complete pipeline is not under stress; certain sections are under stress while adjacent sections are not. Because of these pressures and strains, localized electrochemical action takes place. The section of the pipe or structure under stress becomes anodic, whereas the unstressed sections become cathodic. In this way, the pipe under stress begins to corrode and weaken because of the action of corrosion.

Corrosion Caused by Nonelectrolytes

Nonelectrolytes are materials that will not conduct electricity. These materials include nonelectrolytic vapors, liquids, and bacterial organisms. Since they do not conduct electricity, they do not, in themselves, cause corrosion.

NONELECTROLYTE GASES AND VAPORS.—Nonelectrolytic gases and vapors usually must be subjected to high temperatures before corrosive action can take place. Hydrogen sulfide causes scaling of iron at temperatures from 1400° to 2000°F. High-chromium alloy steels resist this type of corrosion best. The only remedy for this type of corrosion is to keep the gases away from the metal or use a metal that can resist corrosion.

High-carbon steels are attacked by hydrogen at temperatures above 750°F. This hydrogen combines with the carbon grains in the steel and causes the metal to weaken at the grain boundaries between the iron and carbon.

Oxygen will combine directly with most metals at high temperatures. The temperature at which oxygen will combine with the metals depends mostly upon the type of metal. In the process of cutting iron with an oxyacetylene torch, the oxygen combines with the iron.

NONELECTROLYTIC FLUIDS.—Nonelectrolytic fluids include such liquids as pure water, lubricating oils, fuel oils, and alcohols. These fluids do not cause corrosion, but corrosion does occur in storage tanks that contain these liquids and in pipelines that carry them. The corrosion is not caused by the nonelectrolyte liquids, but by the foreign products in them. For example, if impure water is introduced into an oil pipeline, the water will cause the inside of the

pipe to corrode. The water collects on the inside of the pipe because the pipe is usually cooler than the oil. In a storage tank, the water will settle to the bottom of the tank because water is heavier than oil, and will cause the bottom to corrode. Hydrogen sulfide and sulphur dioxide may also be introduced into the pipeline to add to the corrosiveness of the water that collects on the metal. The only way to prevent corrosion from this source is either to coat the inside of the pipeline and tanks with a protective film or to remove the water from them.

Bacterial Organisms

Bacterial organisms may also cause microbiological corrosion. Colonies of bacteria that live close to the metal surface in stationary slimy deposits produce corrosive substances such as carbon dioxide, hydrogen sulphide, ammonia, and organic and inorganic acids. These corroding substances are found only in the locality of the colony and may be undetected in the surrounding water or soil. Bacteria that cause corrosion in this way need to produce only small amounts of corrosive products for localized attack. However, colonies of bacteria that do not produce corrosive products may act as a protective film around the metal, causing unequal distribution of electrical potential, which gives rise to local anodes and cathodes. In this way, the production of local cells will cause increased corrosive action.

Biological corrosion is extremely difficult to control, since the organisms are very resistant to normal methods of sterilization. Probably the most logical method to reduce microbiological corrosion is by the use of some barrier coating between the environment and the metal.

Corrosion Caused by Electrolytes

An electrolyte is any substance that conducts electricity. It conducts electricity because it contains ions that carry electrical charges, either negative or positive, that move in electrical fields. Some of the more important electrolytes are discussed in the following paragraphs.

ATMOSPHERIC CONDITIONS.—Corrosion due to atmospheric conditions is caused mainly by the water in the atmosphere. Pure water is a nonelectrolyte, but because water is a universal solvent, it is not found to be pure very often. Rain water is often considered to be pure, but this is not true. As rain falls to the ground, it dissolves

gases out of the atmosphere and becomes impure. For this reason, any water vapor in the atmosphere is also impure. If a piece of metal is exposed to atmospheric air, and the metal is cooler than the air, water vapor from the air will collect on the surface of the metal. The layer of water on the metal may be so thin that it cannot be seen; but there is enough of it, if impure, to start corrosion. In this case, when the gases dissolve into the water, the water becomes an electrolyte. When metal is exposed to an electrolyte, galvanic cells are produced on the surface of the metal, since there are impurities in it. Each one of these cells starts to act on the metal, causing corrosion by electrochemical action.

WATER AND WATER SOLUTIONS.—If metal is exposed to water or water solutions, corrosion is likely to occur if the water or metal is impure. If the water or metal is pure, corrosion probably will not occur; however, these conditions seldom exist in nature. Impurities in the water and metal produce galvanic cells that cause corrosion.

CHEMICAL AGENTS.—Chemical agents such as acids and salts also cause corrosion. When these agents are present in the environment, direct chemical attack on metal is the result. For example, if a piece of zinc is exposed to hydrochloric acid, a definite chemical reaction takes place. The zinc and hydrochloric acid combine, producing zinc chloride and hydrogen. This action continues until the zinc is completely dissolved or the acid is too weak to act on the zinc. Corrosion causes the zinc to dissolve.

Another example that may be used to illustrate corrosion through the use of a chemical agent is to place aluminum in a lye solution. The lye will pit (corrode) the aluminum as long as chemical action continues between the aluminum and lye.

MATERIALS LEAST LIKELY TO BE AFFECTED BY SCALE AND CORROSION

Whenever installing various types of plumbing equipment in areas where corrosion is active, you should select equipment made of materials least affected by corrosion. To prevent electrochemical action in plumbing equipment, the equipment should be made of materials that are not affected by electrolysis. Plastic materials such as polyethylene polyester and polyvinyl chloride are not acted upon by corrosion. Glass is another material that is not acted on by corrosion. (This

is why hot-water tanks are lined with glass.) Other materials used for the manufacture of pipe that resists corrosion are vitrified clay, cement, fiber, asbestos, and rubber. Glass fibers reinforced with epoxy or polyester resins are also resistant to corrosion.

Dielectric bushings may be installed to stop electrolytic action in plumbing systems or wherever dissimilar metals are used. These bushings are made of nylon and are usually colored. They withstand pressures to 100 psi and temperatures up to 300°F. The bushings are usually placed in pipe systems as recommended by the manufacturer. Some metals least likely to be affected by corrosion are copper, brass, Monel, and stainless steel.

COATINGS AND WRAPPINGS FOR CORROSION PROTECTION

Coatings and wrappings are commonly used to combat corrosion on exterior piping systems. There are many different types of coatings such as asphalts, coal tars, plastics, mastics, greases, and cements. These coatings are considered to be insulating materials, but each is not effective in all environments. Each one was developed for a certain type of corrosive environment.

Asphalt Coatings

Asphalt base coatings are the most common type of protective coatings used. They are produced from petroleum residue and natural sources. Asphalt base coatings can take considerable abrasion, impact, and temperature changes without creating a corrosive condition. However, they absorb a considerable amount of water and dissolve easily into a form of petroleum product.

Coal Tar Coatings

Coal tar coatings are commonly used on pipelines. They possess continuity, hardness, adhesion, and corrosion resistance. Coal tar coatings are less expensive than asphalt coatings. They do not have a very good impact resistance, and a wide temperature change often causes the surface to crack.

Paint Coatings

Some of the most important paint coatings are coal tar, asphalt, rubber, and vinyl.

Coal tar paints have the outstanding characteristics of low permeability and resistance to electrolytic reaction. They are not affected by the action of water. These paints are recommended for piers, marine installations, flood control structures, sewage disposal plants, and industrial concrete pipelines.

Asphalt paints are weather resistant and durable against industrial fumes, condensation, and sunlight action. Because of their resistance against water solvency, they are used on steel tanks and concrete reservoirs.

Rubber base paints are very resistant to acids, alkalies, salts, alcohols, petroleum products, and inorganic oils. The resistance of these products makes them ideal for use on the inside of metallic and concrete storage tanks. If these structures are submerged in water or are under ground, a special form of this paint should be used because of condensation.

Vinyl paint is one of the many synthetic resin base paints. These paints dry to a film that is tough, abrasionproof, and highly resistant to electrolysis. They are odorless, tasteless, nontoxic, and nonflammable. The film is especially resistant to oils, fats, waxes, alcohols, petroleum solvents, formic acid, organic acids, ammonium hydroxides, and phenols. Because of these characteristics, vinyl paint is very applicable for tanks, pipelines, wellheads, offshore drilling rigs, pipe used in oil industries, railroad hopper cars, dairy and brewery equipment, storage tanks, and concrete exposed to corrosive environments.

Grease Coatings

Grease is another material used to form a protective coating on structures. It is usually made from a petroleum base and resembles paraffin or wax. Grease can be applied either hot or cold. However, it must be protected by some type of wrapping to keep the grease from being displaced or absorbed by the backfill soil when it is applied to underground surfaces.

Concrete Coatings

Concrete coatings have been used with success when properly applied to pipelines to be laid in highly corrosive soils, such as areas containing

acid mine drainage or in brackish marshes. Well-mixed concrete, usually a mix of one part portland cement to two parts sand, may be applied to pipelines. The thickness of the coating applied may be up to 2 inches. If the concrete is properly mixed and tamped around the pipe, it may last 40 years. However, concrete has a tendency to absorb moisture and crack, which in many ways limits its use. In fact, in places where the coating cracks, electrolysis immediately starts to corrode the metal. This corrosion can be partially prevented by painting the pipe with a bituminous primer before coating it.

Metallic Coatings

Metallic coatings such as galvanizing (zinc coating) are very effective in protecting metallic structures or pipes against atmospheric corrosion. This type of coating is ideal for cold-water lines and metals exposed to normal atmospheric temperatures. However, metals such as iron corrode rapidly when used in high-temperature equipment because at a critical temperature of approximately 140 °F iron becomes anodic to zinc. This results in the iron's becoming the sacrificial anode that corrodes readily.

Plastic Wrapping

Plastic tapes for wrapping come in rolls. They may be procured in various widths. The tape is wrapped around the pipes before they are laid in the trench. The wrappings are applied by a simple device that is clamped on the pipe and turned by the UT. Pipe joints are wrapped after the pipes are laid in the trench.

GALVANIC CATHODIC PROTECTION

Galvanic cathodic protection is a method used to protect metal structures from the action of corrosion. As explained before, galvanic cell corrosion is the major contributing factor to the deterioration of metal by electrochemical reaction. The area of a structure that corrodes is the anode or positive side of the cell. Corrosion occurs when the positive electric current leaves the metal and enters the electrolyte. Galvanic cathodic protection is designed to stop this positive current flow.

When the current is stopped, the corrosive action stops and the anodes disappear. This type of protection depends upon the neutralization of the corroding current and the polarization of the cathode metal areas.

METHODS OF GALVANIC CATHODIC PROTECTION

Galvanic cathodic protection is a means of reducing or preventing the corrosion of a metal surface by the use of sacrificial anodes or impressed currents. When sacrificial anodes are used, it is known as the galvanic anode method. If impressed currents are used, it is known as the impressed current method. These two methods can be used separately or with each other, depending upon the corrosive characteristics of the electrolyte surrounding the structure.

Galvanic Anode Method

The galvanic anode method of cathodic protection uses an electrode referred to as a sacrificial anode that corrodes to protect a structure. This sacrificial anode is electrically connected to and placed in the same electrolytic area of the structure. The anode used to protect iron or steel structures should be made of magnesium or zinc so it will produce a sufficient potential difference to cause the structure to become a cathode. The action of this type of galvanic protection causes the electric current to flow from the sacrificial anode through the electrolyte to the structure to be protected. The electrical connection between the two metals completes the circuit and allows the current to return to the corroding metal. The sacrificial anode becomes the anode of the established dissimilar metal galvanic cell, and the structure to be protected becomes the cathode. The current from the sacrificial anode is intense enough to oppose or prevent the positive current from leaving the anodes in the structure to be protected. These structure anodes are then suppressed, and the metal in the structure becomes a cathode. The prevention of these positive currents from the anodic areas in the structure reduces the corrosion rate to almost zero.

Galvanic cathodic protection is used in areas where the corrosion rate is low and electric power is not readily available. A typical example of

galvanic cathodic protection is shown in figure 7-14.

Impressed Current Method

The impressed current method of cathodic protection is designed to protect large metal structures located in corrosive areas. With this method of protection a source of alternating current is required. Also, a rectifier is needed to obtain the required direct current potential.

The basic principle of the impressed current method is merely the application of the galvanic cell reaction. The component parts of this method are the cathode (the metal structure to be protected), the anode (made of suitable anodic material), the electrolyte or ground (the ionized corrosive material), and the rectifier and various connections that serve to complete the electrical circuit. The operation of this method depends on the rectifier forcing direct current from the anode through the electrolyte (ground) to the metal structure to be protected. This method causes the metal structure to be the cathode, suppresses the anodic currents from it, and, in turn, prevents corrosion of the structure. An impressed current method of cathodic protection is shown in figure 7-15.

FIELD TEST EQUIPMENT FOR CATHODIC PROTECTION

The items of field test equipment that the UT uses to make tests when installing, operating, and

maintaining cathodic protection systems are the volt-millivoltmeter, multicomination meter, resistivity instrument, buried pipe locator, and the protective coating leak detector. This equipment is discussed in the following paragraphs.

Volt-Millivoltmeter

In corrosion and cathodic protection testing in the field, it is necessary to measure the potential of the structure being investigated as compared to the earth along the structure and to other metallic structures. It is also necessary to measure the potential of rectifiers, batteries, galvanic anodes, and sometime potentials along the earth's surface to determine the distance being protected. The potentials may vary from millivolts to 20 volts or more. Various types of voltmeters are used for this purpose. One of these instruments is the volt-millivoltmeter. It is a recording instrument designed with a chart that makes one revolution in 24 hours. The instrument will record the variations in potential and reveal the electrolytic conditions around a structure.

Multicomination Meter

The multicomination meter is used quite often in cathodic protection work. It is designed as a combination unit and actually consists of more than one instrument. The meter can be used as a high-resistance voltmeter, an ammeter, a

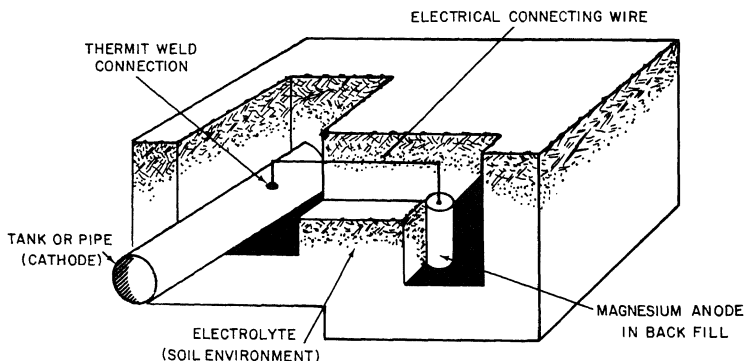


Figure 7-14.—Galvanic cathodic protection.

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milliammeter, a low-resistance voltmeter and millivoltmeter, and a potentiometer voltmeter.

The multicomination meter may be used to measure galvanic anode current between an anode and structure, galvanic current between structures, and potentials as with other types of voltmeters and millivoltmeters.

Resistivity Instruments

Resistivity measuring instruments are units used to test the corrosive action of a soil. Tests regarding soil corrosivity are necessary when designing cathodic protection systems. Information from these tests is used to locate the most corrosive areas where a pipeline is to be laid and the most corrosive areas of an existing pipeline. It is also used to decide the location for anode beds.

One of the simplest methods for making a resistivity test is to use a single probe resistivity meter. It consists of a probe with two electrodes, an indicating instrument, switches, and the required wiring. To use this instrument, the probe is inserted into the ground and current is applied to it. The indicating instrument gives a reading that indicates the corrosiveness of the soil.

Buried Pipe Locator

In the field of cathodic protection work, it is necessary to locate pipes in order to locate interferences in the cathodic protection system. An electronic pipe locator is used for this purpose. The main components of the locator are the directional transmitter and the directional receiver. Each one of these units is carried by an operator. The operators are usually about 30 feet apart. During actual operation the transmitter sends out signals which travel along the pipeline. The receiver, in turn, picks up these signals in varying intensities, depending on the distance the operators are from the pipe. When both operators are directly over the pipe, a maximum response is obtained in the phones and on the visual meter of the receiver. Most pipe can be located easily and accurately in this manner.

Protective Coating Leak Detector

A protective coating leak detector (referred to as a *holiday detector*) is used to detect the imperfections (holidays) in pipe coatings. The holiday leak detector is an instrument that operates on an electric current. When it is being

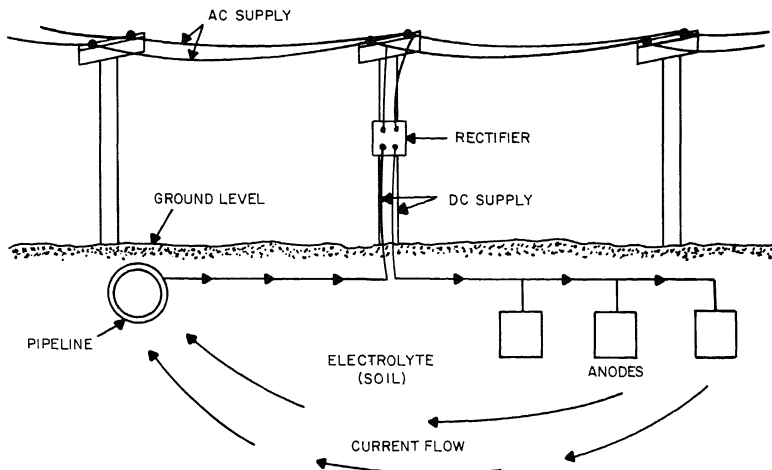


Figure 7-15.—Impressed current method of cathodic protection.

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moved along a pipe that is covered by a coating or wrapping, a completed circuit between it and the pipe reveals a holiday and causes a bell to ring, or a bulb to light, or a buzzer to sound.

MAINTENANCE OF ANODE SYSTEMS

The anode system of cathodic protection requires very little maintenance, because it does not have a power source and does not have to be regulated.

Magnesium and zinc anodes used in the anode system sometimes suffer local or self-corrosion that reduces their efficiency. When their efficiency drops to a minimum, they must be replaced. Anode life varies from 5 to 30 years, depending upon the type of anode used. It is conservative to figure that about 17 pounds of magnesium or 25 pounds of zinc are wasted away by electrolysis from an anode per ampere year. Test stations should be installed in the anode system so the effectiveness of the cathodic protection can be determined.

MAINTENANCE OF IMPRESSED CURRENT SYSTEMS

The impressed system of cathodic protection requires considerably more maintenance than the anode system. This is because an electrical current is used for the operation of the system. The current may come from any alternating current source. Wind-driven generators can be used to furnish the alternating current when it is not readily available. The transformer rectifier used in the system requires much less maintenance and servicing than other sources of current. However, systematic maintenance procedures must be used to keep these units in operating condition.

The transformer rectifier set consists of two units, a transformer and rectifier. The transformer

is used to step the high voltage down to a value of 12 to 40 volts. The rectifier is used to change alternating current to direct current. Connections on this unit must be kept tight.

The materials most often used for anodes with impressed current are aluminum, high-silicon cast iron, and graphite. Scrap iron and steel may be used for anodes, since they waste away at a rate of 20 pounds per ampere year. Anodes must be replaced when they are totally wasted away.

Insulated wire that resists electrolytic action must be used to make the connections between the anodes and the structures to be protected. The insulation on existing current-carrying lines should be checked. If deterioration is evident, the wires should be replaced. Overhead electrical lines should be checked also to see that they are securely fastened to the poles and that the connections are tight.

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CHAPTER 8

FIRE PROTECTION SYSTEMS

Learning Objective: Recognize the characteristics of various types of fire protection systems as applied to the installation and maintenance of these systems.

This chapter describes the operation, testing, and maintenance of fire protection systems for buildings and other structures. Fire protection systems include automatic sprinkler systems, standpipe and hose systems, foam extinguishing systems, gaseous extinguishing systems, and chemical extinguishing systems. Fire alarm and detection equipment are discussed showing the relationship between the mechanical and electrical components of these systems.

Because of the large number of manufacturers and models of fire protection systems, the Utilitiesman cannot be expected to acquire a detailed knowledge of all installation and maintenance considerations involved with this equipment. The principles presented in this chapter apply on a general basis for any given device or system you may encounter in the field. Refer to the manufacturer's manuals, job specifications, the *National Fire Protection Association Codes*, and local codes for in-depth information regarding specific types of equipment.

AUTOMATIC SPRINKLER SYSTEM CHARACTERISTICS

Automatic sprinkler systems automatically distribute water upon a fire in sufficient quantity to either extinguish the fire or prevent its spread. All sprinkler systems have three basic components. They are (1) a water supply, (2) a piping network to carry the water, and (3) sprinklers that distribute the water. This section discusses the three major categories of sprinkler systems with their related

controlling devices and fittings and the sprinklers that may be chosen for installation into these systems.

TYPES OF SPRINKLER SYSTEMS

There are several types of sprinkler systems. The most common ones are the wet pipe, the dry pipe (that uses the differential dry pipe valve, the low-differential dry pipe valve, or the mechanical or latched-clapper dry pipe valve), the water deluge, the pre-action, and the combined systems.

Wet Pipe System

The wet pipe sprinkler system is the most common type. This system has automatic sprinklers attached to a piping network with water under pressure at all times. The sprinklers are actuated by the heat of a fire. A wet pipe system is generally used when there is no danger of the water in the pipes freezing or when there are no special conditions that require a special purpose sprinkler system.

The wet pipe sprinkler system may have an alarm check valve (figs. 8-1 and 8-2). This device is used to maintain a constant pressure on the system piping network above the valve. When there is a fire, the flowing water causes the clapper assembly inside the alarm check valve to open. This permits a portion of the water to flow through a port in the valve that is connected to an alarm device. To prevent false alarms, a retard chamber is usually placed in the piping between the alarm check valve and the alarm device.

Dry Pipe System

In a dry pipe system, the pipes normally contain either air or nitrogen under pressure. Dry pipe systems are used in areas where the water in the pipes is subject to freezing.

A dry pipe valve acts as a control between the water supply and the air under pressure in the piping network. The dry pipe valve must be in a

heated enclosure because pressurized water is at the underside of the valve. A small amount of water, called priming water, is also inside the dry pipe valve itself to ensure a tight seal of the clapper and to keep the rubber gaskets pliable. The valve is usually made so that a moderate air pressure holds back a much greater water pressure. There are several types of dry pipe valves.

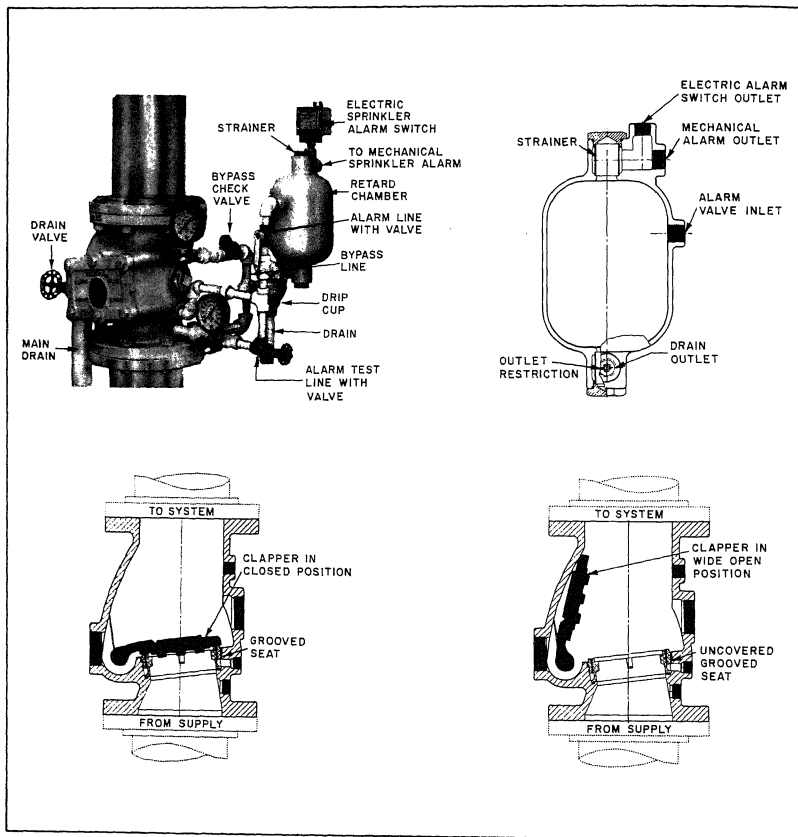


Figure 8-1.—Alarm check valve.

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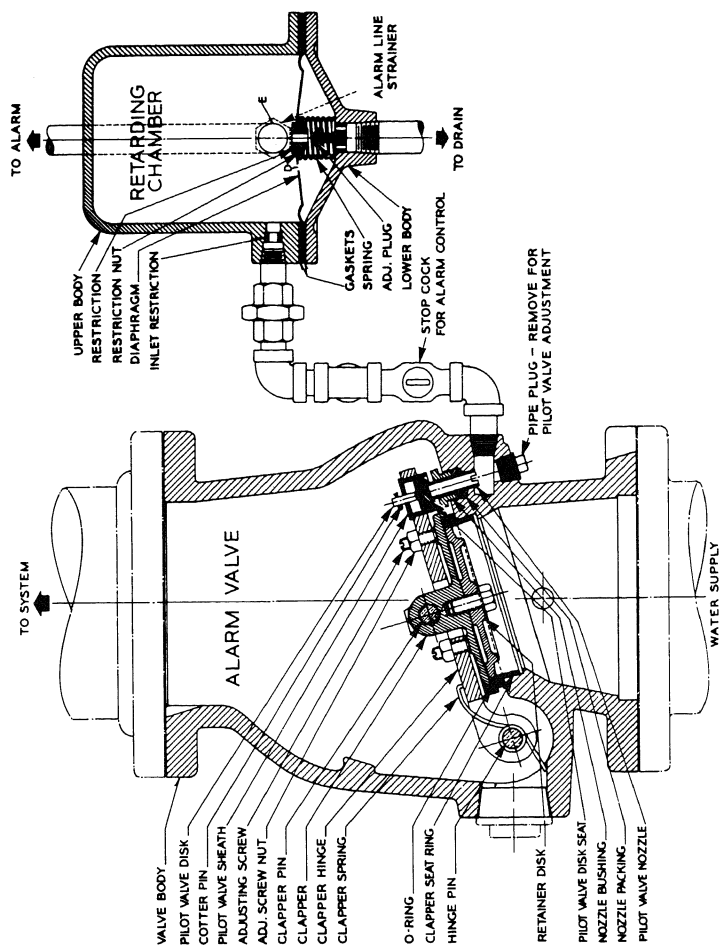


Figure 8-2.—Alarm check valve (section).

DIFFERENTIAL DRY PIPE VALVE.—The differential dry pipe valve (fig. 8-3) has a large clapper on the air side that bears directly on a smaller water side clapper. The differential between the areas of the two clappers is approximately 6 to 1. Therefore, relatively low air pressure can hold back a much larger water pressure. For example, 30 pounds per square inch (psi) air pressure can hold back 180 psi water pressure.

To eliminate an accidental trip of the valve and false alarms, air pressure should be maintained at least 20 psi greater than the calculated trip pressure of the dry pipe valve. This is based on the highest normal water pressure of the supply system.

In operation, when there is a fire the heat actuates the sprinklers and allows the air pressure to be relieved from the piping network. The differential is destroyed. The water pressure below the valve opens the clapper, allowing water to flow through the piping to the open sprinklers. This

operation has an inherent time delay between the actuation of the sprinklers and the application of water to the fire. This delay can be shortened by adding an accelerator or an exhaustor to the dry pipe system.

The accelerator (fig. 8-4) allows air from the system's piping to enter the intermediate chamber in the dry pipe valve, destroy the differential, and open the clapper.

The exhaustor (fig. 8-5) opens and exhausts air from the piping system faster than through the sprinklers, destroying the differential sooner.

LOW-DIFFERENTIAL DRY PIPE VALVE.—Occasionally the water supply to dry pipe valves contains debris. With a differential dry pipe valve, the high velocity of water entering the system when the valve trips can carry the debris into the system, plugging system piping and sprinklers. If debris in the water is a problem, the low-differential dry pipe valve (fig. 8-6) may be useful.

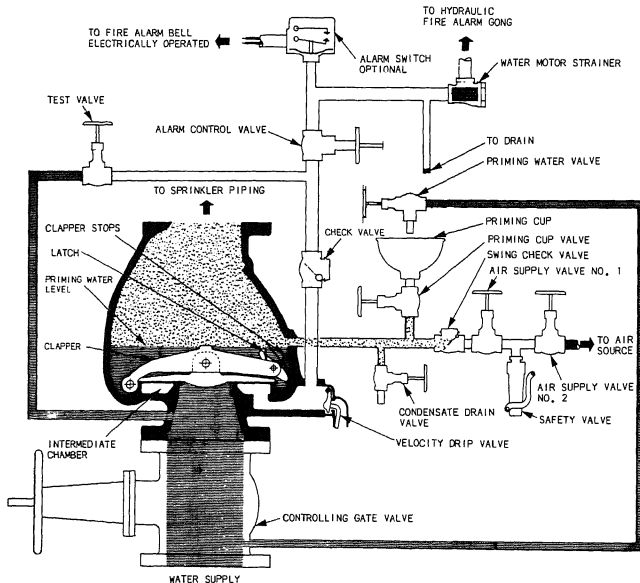


Figure 8-3.—Differential dry pipe valve.

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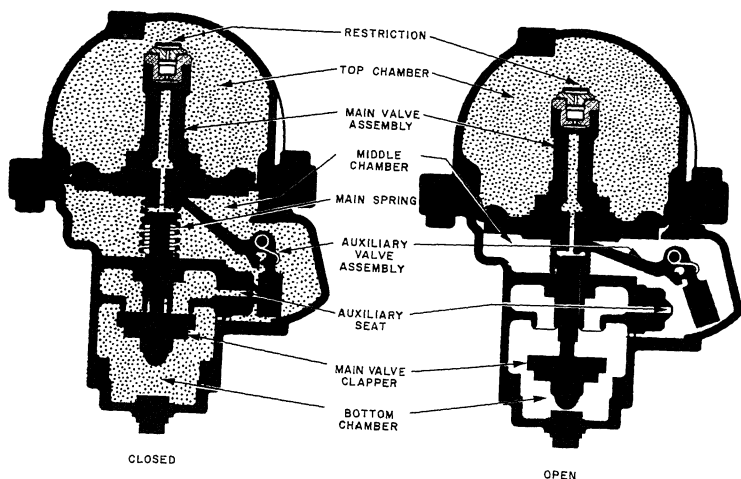


Figure 8-4.—Dry pipe system accelerator.

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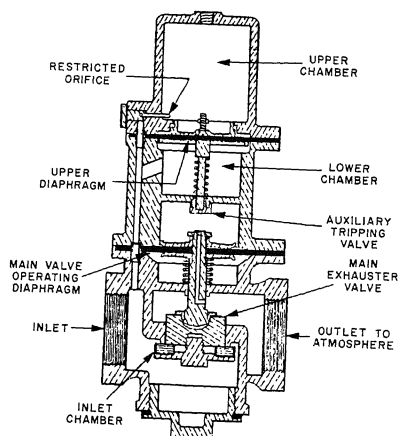


Figure 8-5.—Dry pipe system exhaustor.

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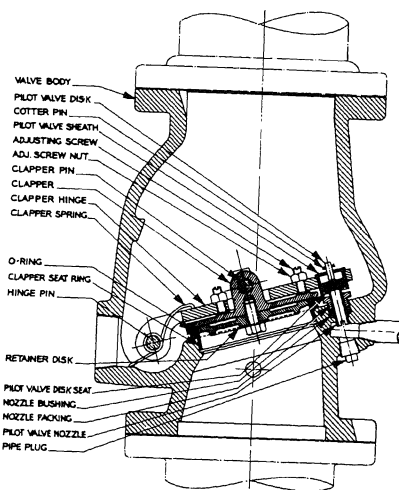
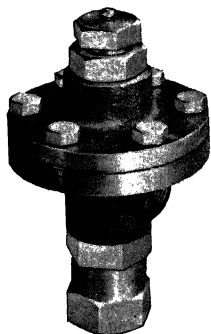


Figure 8-6.—Low-differential dry pipe valve.

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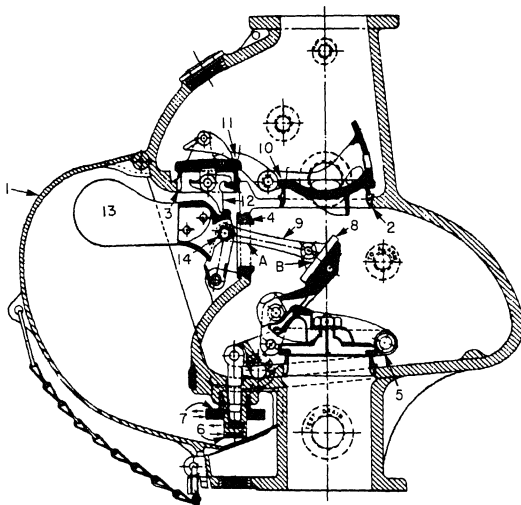


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Figure 8-7.—Air pressure maintenance device.

The clapper in the low-differential dry pipe valve is only slightly larger on the air side than on the water side. The air pressure in the system is maintained approximately 15 to 20 psi greater than the water pressure. Because the sprinkler system piping contains air pressure about equal to the water pressure, the sudden rush of water is slowed and only a slight amount of water is diverted into the branch lines, which do not have operating sprinklers after the valve opens.

With either a differential or low-differential dry pipe valve an automatic air maintenance device (fig. 8-7) must be used to maintain air pressure and prevent accidentally tripping the dry pipe valve. Also, an automatic drain or high-water-level alarm is required for the priming water level so the water does not accumulate. (If there is too much priming water, the valve cannot operate.)



- | | |
|--------------------------------|------------------------------|
| 1. BALL WEIGHT COVER | 8. INTERMEDIATE CLAPPER |
| 2. WATER AND AIR CLAPPER SEATS | 9. INTERMEDIATE CLAPPER LINK |
| 3. AUXILIARY CLAPPER SEAT | 10. AIR CLAPPER |
| 4. INTERMEDIATE CLAPPER SEAT | 11. AUXILIARY CLAPPER |
| 5. WATER CLAPPER | 12. TRIGGER |
| 6. ADJUSTING NUT | 13. BALL WEIGHT |
| 7. ADJUSTING SCREW LOCKNUT | 14. BALL WEIGHT PIN |

Figure 8-8.—Mechanical dry pipe valve.

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MECHANICAL OR LATCHED-CLAPPER DRY PIPE VALVE.—The mechanical or latched-clapper dry pipe valve operates under the same theory as other dry pipe valves. It has system air pressure against a small disk, diaphragm, or clapper. An arrangement of levers, links, and latches on the valve clapper provides the leverage for the closing force placed on the water clapper (fig. 8-8).

Water Deluge System

A water deluge system (fig. 8-9) is used where there is an extra hazard, such

as areas where flammable liquids or propellants are handled or stored, or where there is a possibility that a fire might grow faster than ordinary sprinkler systems can control. These systems are also often used in aircraft hangars where ceilings are unusually high and where drafts may deflect the direct rise of heat so that sprinklers directly over the fire would not open promptly but others, at some distance away, might open without having any effect on the fire.

In the water deluge system, all sprinklers connected to the piping network are open and the water supply is controlled by a water deluge

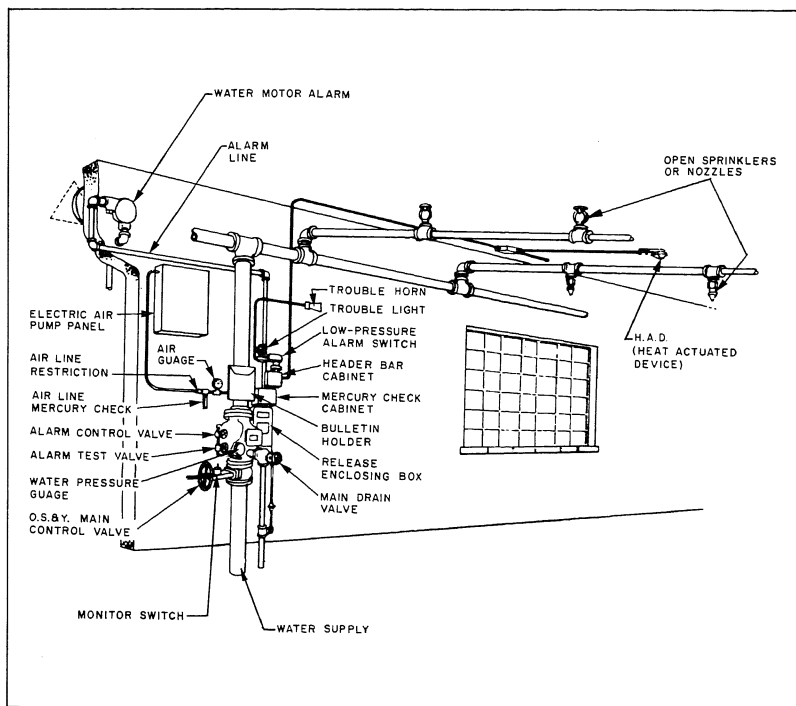


Figure 8-9.—Deluge system.

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valve (fig. 8-10). The water deluge valve remains closed until a fire is detected by a heat-actuated device that in turn causes the valve to open. Heat-actuated devices (H.A.D.) can be either mechanical or electrical in operation. They are discussed in further detail later in this chapter.

The deluge system has a time delay between detection of a fire and the discharge of water at the sprinkler heads. This delay is due to the time required to operate the valve and fill the piping network with water, similar to the dry pipe system. To reduce the delay, the deluge system may be pre-primed by filling the piping network with water downstream from the deluge valve. To prevent water from escaping from the sprinklers, pre-prime plugs (fig. 8-11) are placed on the sprinklers. These plugs blow out of the sprinklers at approximately 20 psi water pressure.

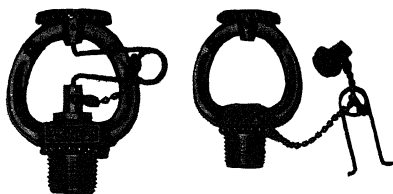
Pre-Action System

A pre-action system differs from a deluge system only in that it has normally closed automatic sprinklers. When the fire detecting device is actuated, the water control valve opens and admits water into the piping system. The system then acts the same as a wet pipe system. Individual sprinklers are opened by the heat of the fire. The advantage of the pre-action system is that the probability of inadvertent water

discharge is minimized because operation of both the detection system and automatic sprinklers is necessary for discharge of extinguishing water.

It is incorrect to refer to pre-action systems as dry pipe sprinkler systems. It is true that the pre-action system piping does not contain water. However, the term *dry pipe system* refers to the type of sprinkler system and the type of water control valve that operates the system.

There are two types of pre-action systems. First is the supervised system, which has air introduced into the system piping at a pressure of approximately 5 psi. This air pressure "supervises" the piping to detect leaks. The pressure switches used for detection of low air pressure on



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Figure 8-11.—Sprinkler pre-prime plugs.

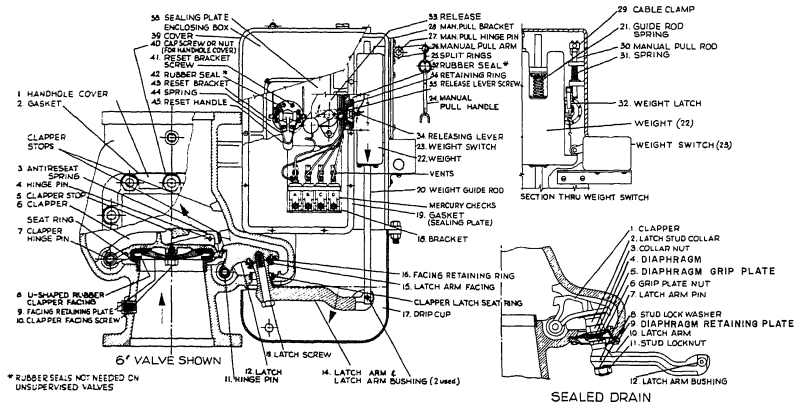


Figure 8-10.—Deluge valve.

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the supervised system should record in inches of water rather than pounds per square inch. The second system is the unsupervised pre-action system. It has no means of continuous monitoring.

Combined System

A combined system (fig. 8-12) is a special purpose arrangement using two modified dry pipe valves connected to tripping devices and piped in parallel to supply water to the same sprinkler system. The piping network is filled with air under pressure. When a fire is detected, an exhaustor at the end of the system opens and releases the air within the system. The system then operates the same as a pre-action system. However, if the detection system fails, the combined system acts the same as a dry pipe system and allows water to be admitted to the system when the sprinklers open, discharging the air from the piping network.

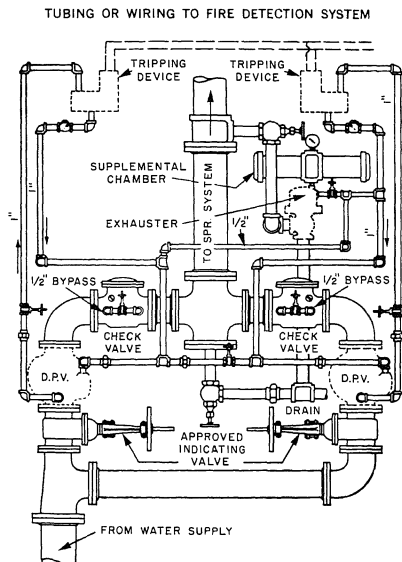


Figure 8-12.—Combined system header arrangement.

TYPES OF SPRINKLERS

Sprinklers are nozzles placed at intervals along the piping network to distribute a uniform pattern of water on the area being protected. To attain maximum efficiency, the stream of water must be broken into droplets. A deflector (part of the frame of the sprinkler) breaks up the water.

You, as a UT, will generally install sprinklers to meet the specifications and plans of a project. When you require more information on proper locating of sprinklers, refer to the *National Fire Protection Association Code Book Number 13* (NPFA #13), entitled *Installation of Sprinkler Systems*.

Automatic sprinklers are designed for specific applications based on orifice size, deflector design, frame finish, and temperature rating. Sprinklers have orifices ranging in size from 1/4-inch to 1/2-inch diameter graduated by 1/16-inch increments. There is also one 17/32-inch size orifice. Deflectors give different patterns of water distribution and allow the sprinkler to be placed in various locations such as upright, pendent, or sidewall (fig. 8-13). Next, sprinkler frames may

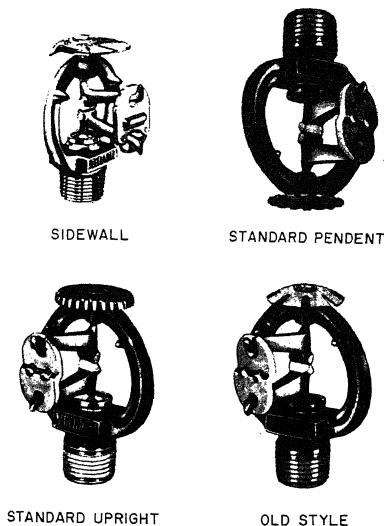
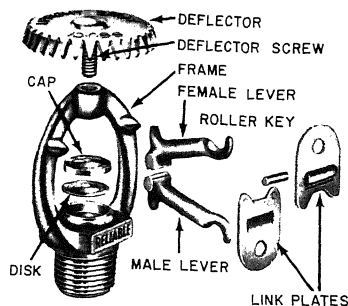


Figure 8-13.—Sprinkler deflector styles.

be plated for appearance or they may be coated for protection from an adverse environment. For example, sprinklers that will be used in corrosive atmospheres are either lead- or wax-coated. Finally, automatic sprinklers are normally held closed by heat-sensitive elements that press down on a cap over the sprinkler orifice and are anchored by the frame of the sprinkler. The heat-sensitive elements melt and release at different temperatures depending on application. Sprinklers are color coded to identify the temperature range rating of the fusible element (table 8-1). Color coding is not required for plated sprinklers, ceiling sprinklers, or similar decorative types.

There are basically four types of *release mechanisms* for automatic sprinklers. They are the fusible link, frangible bulb, frangible pellet, and bimetallic element.

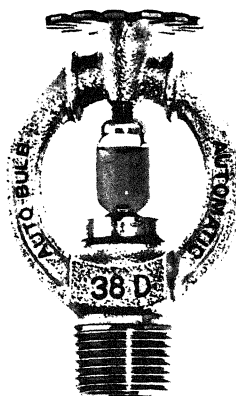


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Figure 8-14.—Fusible link automatic sprinkler.

The *frangible link sprinkler* (fig. 8-14) is kept closed by a two-piece link held together by a solder with a predetermined melting point. When the solder melts, the levers pull the two-piece link apart and fly away from the sprinkler. Pressure in the piping network pushes the cap from the orifice of the sprinkler to discharge water.

The *frangible bulb sprinkler* (fig. 8-15) has a small bulb made of glass between the orifice cap and the sprinkler frame. The bulb is partially filled with a liquid. Air fills the remaining space. Heat from a fire will cause the liquid to expand against the air causing the glass bulb to shatter and opening the sprinkler for water discharge.



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Figure 8-15.—Frangible bulb automatic sprinkler.

Table 8-1.—Sprinkler Temperature Ratings

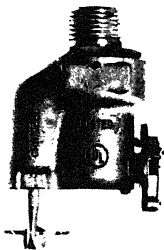
MAXIMUM AMBIENT CEILING TEMPERATURE (°F)	TEMPERATURE RATING (°F)	TEMPERATURE CLASSIFICATION	SPRINKLER COLOR CODE
100	135 to 170	Ordinary	Uncolored
150	175 to 225	Intermediate	White
225	250 to 300	High	Blue
300	325 to 375	Extra High	Red
375	400 to 475	Very Extra High	Green
475	500 to 575	Untrahigh	Orange

A *frangible pellet sprinkler* (fig. 8-16) has a rod between the orifice cap and sprinkler frame. The rod is held in place by a pellet of solder under compression. When the solder melts, the rod moves out of the way of the orifice cap. The cap is pushed off by the water pressure in the piping network.

The *bimetallic element sprinkler* (fig. 8-17) uses a disk made of two distinct metals as a heat-sensitive element. When the sprinkler is off, the disk maintains pressure on a piston assembly. When a fire occurs and the temperature reaches the sprinkler's rating, the disk flexes and opens, releasing pressure on the piston assembly and allowing a small amount of water to bleed out of the piston chamber faster than it can be replaced through a restrictor. The water pressure in the piping network pushes the piston down and allows water to discharge from the sprinkler. When the temperature of the heat-sensitive element is reduced, the element returns to its normal position and allows water to pass through the restrictor, filling up the piston chamber, forcing the piston into the closed position, and stopping water discharge. This sprinkler can be

used to automatically cycle on and off as necessary; for example, to put out a rekindled fire.

Other sprinkler heads that do not have release mechanisms include the dry pendent sprinkler, the open sprinkler, and water spray nozzles.



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Figure 8-17.—Bimetallic element automatic sprinkler.

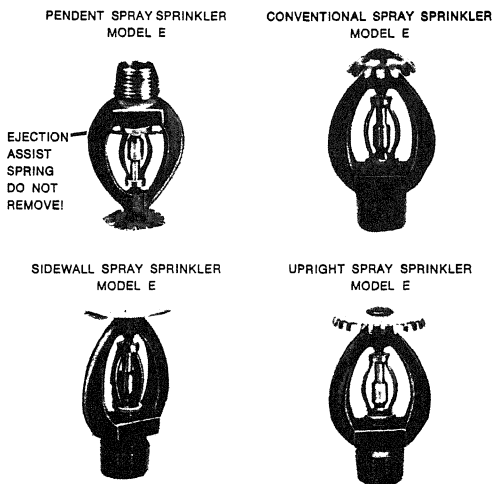


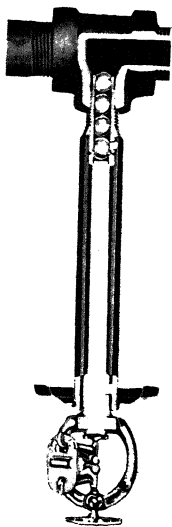
Figure 8-16.—Frangible pellet automatic sprinkler.

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A *dry pendent sprinkler* (fig. 8-18) is used when pendent sprinklers must be placed on dry pipe systems or in wet pipe systems when the area to be protected is subject to freezing (such as a walk-in reefer or outside shop area) and the piping network is installed in a heated area. This sprinkler is fitted with a tube within an attached pipe. The tube holds the water sealing elements in place against a watertight seal at the top of the pipe. When the sprinkler is actuated, the tube drops down and releases the elements through the tube and out the open sprinkler with the water discharge.

Open sprinklers consist only of a sprinkler frame and deflector. They are used on special sprinkler systems such as deluge or rapid reaction systems (fig. 8-19).

Water spray nozzles (fig. 8-20) are used for special application of water in various patterns (for example, wide or narrow angle, long throw or flat patterns). The different patterns may be achieved by either internal or external deflection of the water stream depending on the type of nozzle.



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Figure 8-18.—Dry pendent automatic sprinkler.

SPRINKLER SYSTEM DETECTION AND INDICATING DEVICES AND FITTINGS

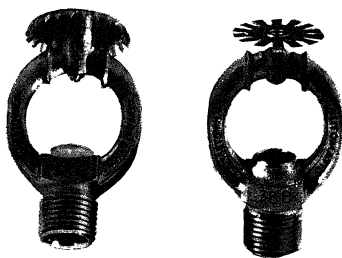
Sprinkler systems have many different controlling devices and fittings. These can be classified as detecting or initiating devices or fittings. Their function is to detect system operation and to initiate system operation or alarm systems connected to the sprinkler system. This section discusses these devices and fittings to aid you in installing and troubleshooting sprinkler systems and understanding the interface between the mechanical and electrical functions of these devices.

Water-Flow Actuated Detectors

Sprinkler water-flow detectors are generally pressure-actuated or vane-actuated. Pressure switches are used on both wet and dry pipe systems. Vane switches are widely used on wet pipe sprinkler systems. They cannot be used on dry pipe systems because the initial rush of water into the pipe could damage the vane and mechanism.

Dry pipe system alarms tend to be slow-acting because it takes time to lose sufficient air through a fused sprinkler to trip the system. Various methods are used to speed up dry pipe systems as discussed earlier.

Wet pipe system alarms have a different problem. Fluctuating water pressure frequently causes flow into a sprinkler system, equalizing the sprinkler system pressure with the supply pressure. Such surges of water or of pressure cause false water-flow alarms if some method of slowing



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Figure 8-19.—Open sprinklers.

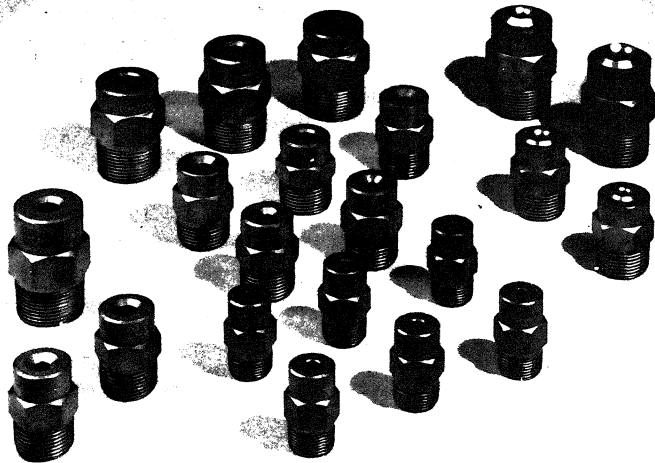


Figure 8-20.—Water spray nozzles.

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down the switch response to the surge is not used. Various retarding techniques are used, some associated with the sprinkler piping and some with the water-flow detector.

The pressure increase type of water-flow detector (fig. 8-21) comes in numerous styles. It is found in wet or dry pipe sprinkler systems. The usual arrangement for switch actuation includes a sealed accordionlike bellows that is assembled to a spring and linkage. The spring-tension setting controls the pressure at which the flow detector is actuated. It can be field adjustable and/or factory set to the desired pressure that activates the electrical switch. If this pressure switch is to be used on a wet pipe system, it is usually mounted at the top of a retarding chamber. This reduces the speed of pressure buildup at the switch. Other styles of this switch incorporate a pneumatic retarding mechanism within the detector housing. The retard time is adjustable to a maximum of 90 seconds. Usual settings are in the range of 20 to 70 seconds. The retard switch is connected to the alarm port of a wet sprinkler system alarm check

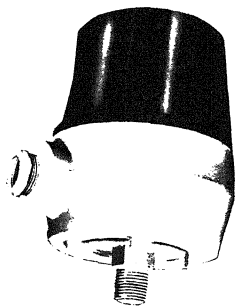


Figure 8-21.—Pressure increase type of water-flow detector.

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valve. It is usually set for a pressure range of 8 to 15 psi.

Pressure drop detectors can be used in wet pipe sprinkler systems equipped with a check

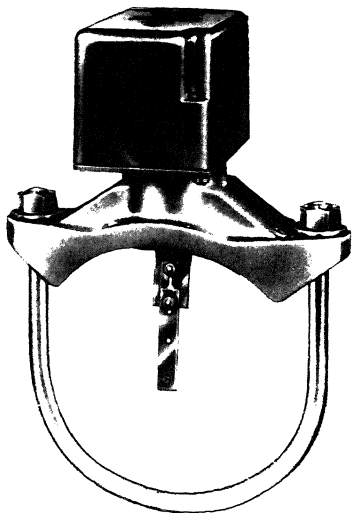
valve (alarm check or swing check) that holds excess pressure on the system side of the check valve. These detectors are frequently used where a water surge or hammer causes false alarms with other types of water-flow detectors. The construction of pressure drop detectors is similar to the pressure increase detectors. The switch for a pressure drop detector is arranged to actuate on a drop in pressure. There is no retarding mechanism or chamber. A typical switch of this type would be adjusted for a normal operating pressure in the range of 50 to 130 psi. The alarm pressure would be adjustable between 10 to 20 psi below normal pressure.

A vane type of water-flow detector (fig. 8-22) is used only in wet pipe sprinkler systems. The detector is assembled at the pipe by drilling a hole in the wall of the sprinkler pipe, inserting the vane into the pipe, then clamping the detector on with U-bolts. When the sprinkler system is actuated by fire, the water flowing through the pipe causes the

vane to move. A mechanical linkage connects the vane to an adjustable retarding device, usually a pneumatic dashpot. The retarding device actuates the alarm switch or switches and/or signal transmitter. The retarding device setting is usually in the range of 30 to 45 seconds. A maximum setting may be as high as 90 seconds if necessary.

The pressure pump/pressure drop type of water-flow detector is used in large sprinkler systems and in those systems with inadequate water pressure to reliably operate one of the other types of water-flow detectors. These detectors are also known as fixed-pressure, water-flow detectors, with pump (fig. 8-23). This detector has a pump, pump motor, and control unit. It is arranged for strap-mounting to the sprinkler system riser. The device provides a water-flow alarm signal, a low system water pressure supervisory signal, and excess pressure in the system to prevent surges in the supply pressure from opening the alarm check valve and causing operation of the water motor gong or other alarm indicators.

A typical detector of this type is adjusted to maintain the system pressure at 25 to 50 psi above supply pressure. A slow leak at the alarm check valve or anywhere in the system will cause the system pressure to drop slowly. When pressure decreases to 2 psi below the preset value, a pressure switch closes, causing the pump to start pumping water from the supply side to the system side of the alarm check valve at a rate of about 1 gallon per minute (gpm). If the total system leaks less than 1 gpm, the pressure switch opens and stops the pump when the preset pressure is reached. However, if the system leaks are greater than 1 gpm, system pressure will continue to drop even with the pump running. If system pressure decreases to 4 psi below the preset value, a trouble pressure switch opens to indicate that there is a leak greater than 1 gpm. If the water pressure continues to drop to 6 psi below the preset value, an alarm pressure switch closes, signaling a water-flow alarm. Some water-flow detectors of this type have an additional switch that disconnects pump power when the supply water pressure drops below 14 psi. This prevents pump burnup in case of total supply shutdown or a break in the supply line.



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Figure 8-22.—Vane type of water-flow detector.

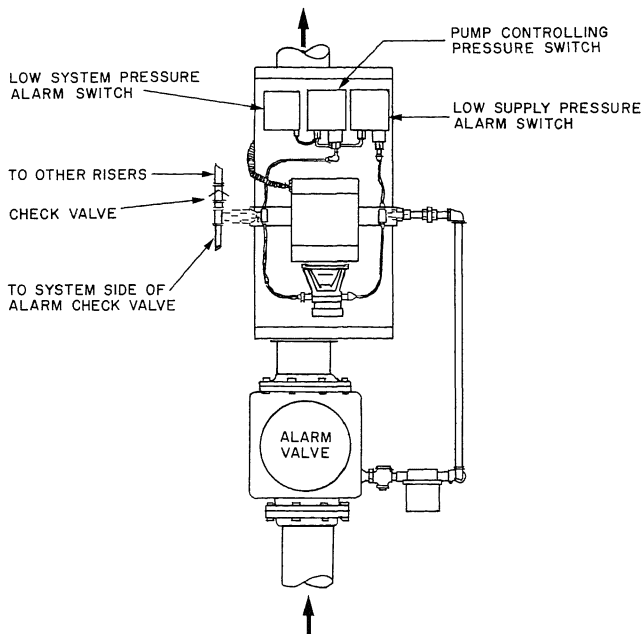


Figure 8-23.—Fixed pressure water-flow detector with pump.

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The electronic pressure drop detector is often used in sprinkler systems that must maintain a high excess system pressure over supply pressure that would delay actuation of a vane type of water-flow detector. It is normally mounted to the riser pipe with a flexible hose connection to the system side of the check valve. This device requires a pressure drop of 5 to 20 ounces per square inch continuing over a period of at least 3 seconds to signal an alarm. A pressure drop at a slower rate or of a shorter duration causes no alarm. A slow pressure drop to 15 psi or less causes a trouble signal indicating a system leak and low supply pressure. Pressure increases do not cause an alarm, but an overpressure condition (200 psi) causes a trouble signal. Trouble signals will also be initiated when the detector's cover is opened, supply voltage is outside normal ranges, and an

internal circuit fails, interfering with detector function.

Supervisory Alarm Initiating Devices

Supervisory alarm initiating devices cause a signal at the supervisory control unit and/or remote receiver when an abnormal fire protection system condition occurs. In general, supervised valves are never closed unless a sprinkler system requires maintenance. Valves that control water flow to a water-flow detector or valves in a sprinkler header room or fire pump room that are normally closed may be supervised. Supervisory devices for normally open valves signal when the valve is closed no more than two turns or 20 percent of its total travel. Supervisory devices for normally closed valves signal when the valve is

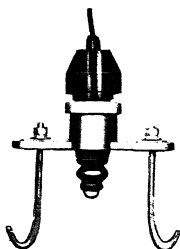
opened no more than two turns or 20 percent of its total travel.

Outside screw and yoke (OS&Y) valve position indicators (figs. 8-24 and 8-25) are firmly attached to the valve yoke (fig. 8-26). The spring-loaded switch-operating lever or plunger rests in a smoothly tapered notch in the valve stem. When the valve is operated, the stem moves in or out; the lever or plunger moves up the incline at the edge of the notch. The switch is actuated before the lever or plunger is out of the notch. This causes a supervisory signal at the control unit and/or remote receiver.

A post indicator valve (PIV) will have a position indicator mounted to it (fig. 8-27). Usually

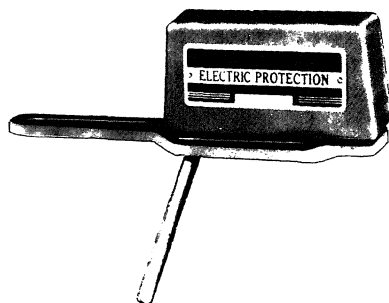
a PIV is located outside the building and may be mounted on the ground or on the building wall. A spring-loaded lever rests against the side of the open/shut indicator, called a target. As the valve is operated, the target moves. The switch follows this movement. The position indicating switch is adjusted to cause a supervisory signal before the operating nut has rotated two turns or 20 percent of its full travel.

Nonrising stem valve position indicators are attached to nonrising stem valves, usually installed underground. The housing of the device is made of a noncorroding material such as brass. The switch itself is a magnetically operated, sealed reed switch. As the valve is operated, the magnet moves away from the reed switch. After the valve has



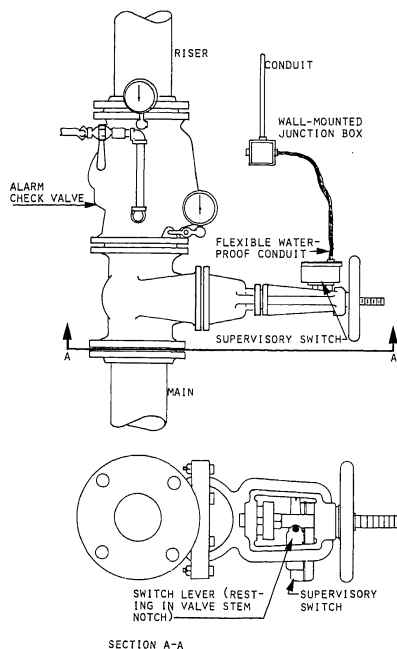
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Figure 8-24.—OS&Y valve position switch (plunger type).



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Figure 8-25.—OS&Y valve position switch (lever type).



87.374

Figure 8-26.—OS&Y valve position supervisory switch installation.

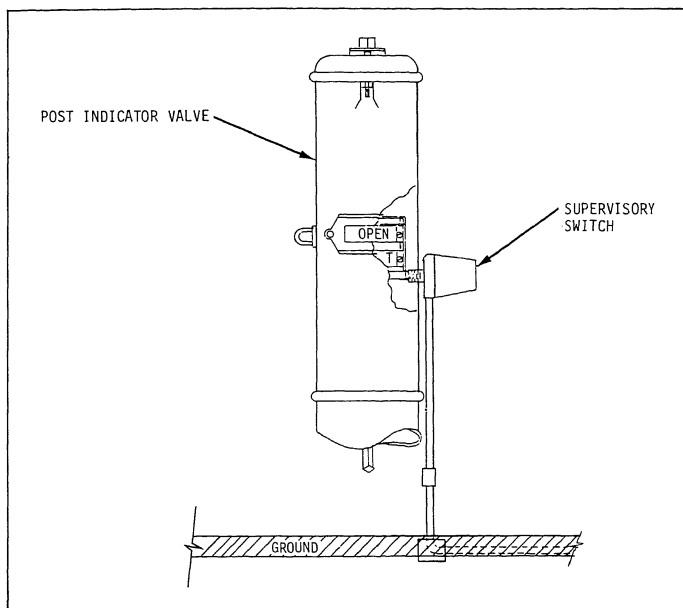


Figure 8-27.—PIV position supervisory switch installation.

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been opened two full turns the magnet is far enough away from the reed switch to actuate it, causing a supervisory signal at the control unit and/or remote receiver.

Water level in sprinkler system reservoirs must be maintained within certain limits. There are usually automatic controls for maintaining the desired water level. Water level supervisory devices cause a supervisory signal when the water level is not maintained between the desired high and low limits.

A float-actuated level indicator (fig. 8-28) is mounted outside on the wall of a tank with its float and lever extended into the tank. The lever arm pivots at the tank wall and rises or falls with the water level. A switch or switches (one for high level, one for low level) are actuated when the float moves outside

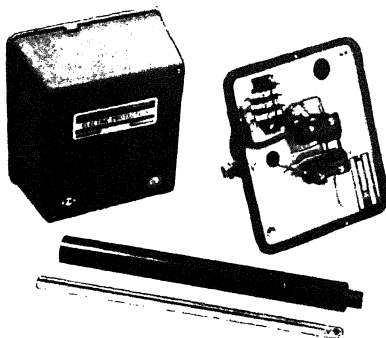


Figure 8-28.—Water level switch (float actuated).

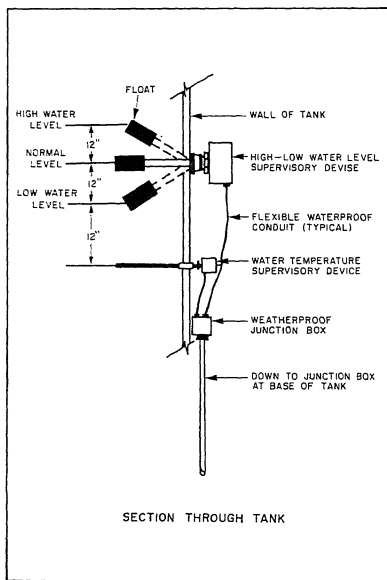
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of normal limits. Figure 8-29 shows a typical high-low water level supervisory device installed in a sprinkler system reservoir.

A pressure-actuated level indicator is physically very similar to the bellows-operated pressure switches used for water-flow detection (fig. 8-21). As the water level changes in a reservoir, the water pressure at the supervisory switch also changes. The switch can be adjusted to actuate when pressure indicates a low water level or a high water level. This device is generally installed in the piping near the bottom of the reservoir.

Electronic level indicators may also be found in some systems. These indicators read the conductivity of water to cause an electrical signal. These devices are most frequently used to sense high water levels. They are not commonly used in fire protection systems.

Temperature supervisory devices are used to prevent water freezing in fire protection systems.



87.377

Figure 8-29.—Installation of water level and water temperature supervisory devices.

Utilitiesmen will most commonly work with low water temperature indicators. These are usually sealed, factory-set thermostats and may be installed in system pipe or reservoirs. The most frequent low temperature setting is 40 °F. Figure 8-29 shows a low water temperature indicator installed in a system reservoir.

You may find other supervisory devices in use. They will usually be specifically designed for a particular system. The principles of operation are generally the same as those already discussed. Physical mounting provisions or other details may vary. Refer to NAVFAC MO-117, manufacturer's manuals, and NFPA #13 for more complete information, when you must install or maintain these devices.

WATER SUPPLY REQUIREMENTS

Water supplies that serve sprinkler systems must be adequate and reliable. To determine the amount of water necessary for a sprinkler system, the rate of flow and pressure needed for effective performance must be known. If additional fire hose streams from outside the building will be required, these should also be included. The combined water needed for all fire-fighting equipment is known as the *fire flow demand*.

An adequate system can deliver the required fire flow for a specified time with normal water consumption at the maximum rate. To be reliable, the system must also be able to deliver the fire flow demand under certain emergency conditions, such as when a supply main or pump is out of service. The desired reliability of the system depends upon the nature of the protected structure (people, property, or mission). Water may be supplied by public or base sources, water tanks, or fire pumps.

For specific information regarding the fire flow demands of sprinkler systems, refer to NFPA #13, chapters 2, 7, and 8. These chapters will give you the information required for the sizing of each particular type of sprinkler system hazard based on residual pressure, acceptable flow rates, and duration times.

INSPECTION, TESTING, AND MAINTENANCE REQUIREMENTS

Sprinkler systems, when properly installed, are an effective means of fire protection for life and property. To make sure these systems are reliable,

periodic inspection and maintenance of system components are required. Inspection should include a visual check and, if possible, a test of the components to be sure a working condition exists. The frequency of the overall testing and inspection process is summarized in table 8-2.

INSPECTION AND TESTING

During inspections of sprinklers, certain conditions indicate maintenance requirements. If these conditions are not corrected, they will reduce the reliability of the system. These conditions and

Table 8-2.—Summary of Inspection and Test Frequencies for Sprinkler Systems

	WEEKLY	MONTHLY	QUARTERLY	ANNUALLY	EVERY 3 YEARS
Check general condition of sprinklers and sprinkler systems				X	
Conduct flow tests of open sprinklers				X	
Conduct main drain tests			X		
Test water-flow alarms		X			
Check air and water pressure in dry pipe systems	X				
Trip-test dry pipe valves				X	
Drain low points in dry pipe systems				X	
Trip-test deluge and pre-action systems				X	X ^{1*}
Trip-test high-speed suppression systems					X
Check general condition of standpipe systems			X		
Perform water-flow tests				X	
Check general condition of hydrants				X	
Check general condition of fire department connections				X	
Check water levels in tanks	X				
Check general condition of water storage tanks				X	
Check water level and air pressure in pressure tanks	X				
Check general condition of pressure tanks				X	
Check tank heating systems				X	
Inspect and test cathodic protection equipment				X	
Start fire pumps	X				
Check fuel supply to engine drivers	X				
Perform fire pump flow tests				X	
Inspect and test controllers				X	
Inspect valves for open position		X			
Conduct general preventive maintenance inspection of valves				X	
Inspect check valves, water-flow meters and backflow preventers					X*
Test pressure regulating and altitude valves				X	

1—Annual trip test may be dry; wet trip test including flow of water through heads/nozzles shall be conducted a minimum of once every 3 years.

*

some remedial actions are discussed in the following sections.

Automatic Sprinklers

Conditions that indicate the need for maintenance for automatic sprinklers include the following:

- Mechanical injury such as bent or loose deflectors or bent frames. Where sprinklers are subjected to continual damage, provide approved sprinkler guards.

- Corrosion such as marked discoloration or hard deposits. Use lead-coated or wax-coated sprinklers to prevent corrosion.

- Overheating causes soldered joints and cracked quartz bulbs to give way. Temperature ratings for soldered link sprinklers should be 50 °F above (for quartz bulb sprinklers 25 °F above) normal room temperature.

- Freezing produces reduced tension in soldered links, bent struts, and distorted caps.

- Loading is deposits of paint or other foreign materials.

- Need for replacement or relocation. Major construction and occupancy changes and changes to heating, lighting, and air-conditioning systems may require relocation or replacement of sprinklers or additions to the system. Changes in sprinkler location and pipe sizes should be based upon an engineering evaluation.

- Where sprinklers are installed in areas where there is stockpiling of materials a clearance of at least 18 inches under the sprinklers is necessary for proper water distribution.

Keep a supply of extra sprinklers for the various types and temperature ratings required and a sprinkler wrench.

Outside Open Sprinklers

When you are servicing outside open sprinklers, you should do the following:

- Visually check the general condition of sprinklers.

- Close windows and doors and take proper precautions to avoid water damage to property before making flow tests.

- Conduct the flow test by opening the control valve.

After making flow tests, remove and clean any plugged or obstructed sprinklers.

Piping and Hangers

In servicing piping and hangers, check for mechanical injury and corrosion. Replace bent or damaged piping and fittings and replace or repair missing or loose hangers. Make sure that piping is not used to support stock, equipment, or other material.

Make sure wet pipe system piping is properly protected against freezing. Before and during freezing weather, check piping of dry pipe systems for proper drainage. During freezing weather, open drains for outside sprinkler systems. Drain water from low point drains and drum drips on dry pipe systems before freezing weather occurs.

Obstructed Piping

When evidence of obstruction of piping has been found, check for the following sources of obstructing material:

- Improperly screened inlets from open bodies of water
- Poorly maintained elevated gravity tanks
- Dead end of extensive water distribution systems
- Poorly installed underground mains
- Highly acid, alkaline, or saline water
- Active chemicals in water supply
- Use of secondhand materials in the sprinkler system
- Frequent operation of systems (especially dry pipe systems) introducing additional foreign material and free oxygen

Alarm Check Valves

Perform a 2-inch drain test quarterly to test alarm check valves. Open the 2-inch drain valve

fully and record pressure on the gauge located below the clapper at the lowest point. Close the 2-inch drain valve and record pressure at the stabilization point. Notice whether pressure returns quickly or slowly. Maintain a continuous record of drain tests. If recorded pressure when the valve is wide open is similar to previous recordings and pressure returns quickly, it is normal.

If recorded pressure when the valve is wide open is significantly lower or pressure is slow to return when the valve is closed, there may be an obstruction in the waterway. Check for the following problems:

- Partially closed valves to sprinkler system
- Obstruction in alarm valve preventing clapper from opening freely

Test local water-flow alarm operation monthly by opening the test connection at the end of the system. Where there is no test connection, the alarm may be tested by opening the bypass valve to the circuit opener or closer or by opening the 2-inch drain valve about two and one-half turns. Do not test water motor alarms during freezing weather. To find principal causes of alarm failures, check for the following:

- Failure of automatic drain on retard chamber to close
- Closed or partially closed valve on piping to alarm devices
- Plugging of bell casings of water motor gongs by foreign material
- Corrosion of moving parts of water motor gongs
- Detachment of shaft couplings from water motor gongs
- Insufficient water flow to operate devices
- Alarm check valve corroded shut (this failure is not common and will not occur when systems are properly maintained)

To find principal causes of false fire alarms, check for the following:

- Improper drainage of retard chamber (correct this by opening the chamber and cleaning or repairing the automatic drain)
- Pressure surges through the alarm check valve

Fill wet pipe sprinkler systems slowly through throttled valves and open the control valve wide after the system has been filled. Be sure there is no drainage from retard chambers. Leakage means that the alarm valve clappers are not seating properly. They require cleaning and possibly overhauling.

Make internal inspections of alarm valves when normal testing procedures indicate the need.

- Examine valve body for tuberculation.
- Check clapper operation—the clapper should move freely without sticking or binding.
- Replace clapper facings as required.
- Resurface seat rings as required.

Dry Pipe Valves and Air Check Valves

Air check valves are special, small, dry pipe valves that are usually connected to a wet pipe system. The alarms are actuated at the wet pipe system riser when the air check valve "trips." To prevent premature operation, the valves should be fitted with an air chamber to maintain at least 50 gallons of air in the chamber and on the system.

Perform the 2-inch drain test quarterly by opening the 2-inch drain valve fully and recording the pressure at the lowest point. Close the 2-inch drain valve and record the pressure at the stabilization point. Notice whether pressure returns quickly or slowly. Maintain a continuous record of drain tests.

If the recorded pressure when the valve is wide open is similar to previous recordings and pressure returns quickly, it is normal.

If recorded pressure when the valve is wide open is significantly lower or pressure is slow to return when the valve is closed, there may be an obstruction in the waterway. Check for partially closed valves to the sprinkler system.

Because dry pipe sprinkler systems are installed in areas where temperatures are expected to drop below freezing, all parts of the system must be airtight and kept free of water. Complete drainage is essential.

Each fall, before freezing season comes, check the pitch of all piping carefully using a spurt level to detect dips and small pockets in the lines. Check for:

- broken, loose, or missing hangers; and
- water in low point drains.

Check air and water pressures weekly. If air pressure losses exceed 10 psi, check the entire system for tightness and eliminate air leaks. Principal checking methods are as follows:

- Put a strong smelling oil, such as oil of peppermint, into the air supply. This will produce a strong odor at the point of leakage.

- Paint fittings with a soapy water solution and watch for bubbles.

Check the temperature of valve enclosure and maintain a temperature above 42°F.

Make certain that the valve between the intermediate chamber and the alarm devices is open on dry pipe valves.

Check drip valves at intermediate chambers, making certain that clappers or balls are in a position to allow drainage. This is done by lifting push rods or by inserting a pencil in the opening. Water leakage through this valve is an indication that the water clapper is not holding tightly to the seat.

Check the air pressure. The air pressure versus water pressure for differential dry pipe valves should be as outlined in table 8-3 unless otherwise specified by the manufacturer's operating instructions. Certain mechanical dry pipe valves are designed to trip at a fixed pressure of 10 to 15 psi. Maintain 30 psi air pressure on these valves.

Basic inspections for accelerators and ex-hausters include the following:

- Check air pressure. The system and the quick-opening device air pressure should be the same.

- Relieve excess pressure in the quick-opening device by opening bleeder valves or loosening air gauges.

If the system pressure is high, relieve the excess pressure through the priming water test valve. Close the valve as soon as pressures balance. To avoid the possibility of tripping the dry pipe valve, do not open the priming test valve more than one turn and keep the valve to the quick-opening device closed while the priming test valve is open.

To make sure that dry pipe valves will operate effectively in fire situations, they should be trip-tested annually as follows:

1. Close the main control valve.
2. Open the 2-inch drain.
3. Open the main control valve until 5 psi pressure shows on the water gauge.
4. Close the 2-inch drain valve slowly.
5. Open the inspector's test connection of the system. Where there is no test connection, use the most remote low point drain.
6. As soon as the dry pipe valve trips, close the main control valve and open the 2-inch drain. This is particularly important in permanently cold areas.
7. Record initial air and water pressures, air pressure at the trip point, and time required for tripping.
8. Examine and clean the dry pipe valve interior. Replace facings and gaskets if needed.
9. Reset the dry pipe valve and the open control valve.
10. When a dry pipe valve fails to trip or when a clapper fails to latch in the open position, notify the person responsible for fire protection so that a qualified sprinkler contractor may be contacted.

To test dry pipe valves you should do the following:

1. Close the main control valve and open the 2-inch drain valve and low point drain valves.

Table 8-3.—Differential Dry Pipe Valve Air Pressure Specifications

MAXIMUM WATER PRESSURE psi	AIR PRESSURE RANGE psi
50	15-25
75	20-30
100	25-35
125	30-45
150	35-50

Close low point drain valves when water stops flowing.

2. Clean clapper facings and seats.
3. Clean the valve interior.
4. Place clappers on seats and make certain the antiwater column latch is in place. Bolt on the cover. Do not use grease or other material to help seat clappers. Fill the system with 10 psi air pressure to blow out any residual water through low point drains.

5. Open valves at the top and bottom of the priming chamber and priming test valves.

6. Admit water to the priming chamber until water flows out of the test valve. Close this valve.

7. Close the priming chamber valves.

8. Admit air pressure to the system.

9. Open the main control valve slowly.

10. Close the main 2-inch drain valve, except where water hammer conditions exist. In this case, leave the 2-inch drain valve open until pressures stabilize.

To check air supply piping, do the following:

Note air pressure within 12 to 24 hours after resetting the dry pipe valve. If air leakage exists, test sprinkler piping for leaks.

Make sure the valves to manually operated compressors are tightly closed. A slow air leak back through one of these valves can trip the dry pipe valve.

Examine restriction orifices in air piping and air pressure regulators, if used, from automatic air compressors to dry pipe valves.

Deluge and Pre-Action Valves

To test deluge and pre-action valves, perform the 2-inch drain test quarterly by opening the 2-inch drain valve fully and recording pressure at lowest point. Close the 2-inch drain valve and record pressure at the stabilization point. Notice whether pressure returns quickly or slowly. Maintain a continuous record of drain tests.

If the recorded pressure when the valve is wide open is similar to previous recordings and pressure returns quickly, it is normal.

If the recorded pressure when the valve is wide open is significantly lower or pressure is slow to return when the valve is closed, there may be an obstruction in the waterway. Check for partially closed valves to the sprinkler system. Check the water pressure and the local water-flow alarm through the bypass connection.

Some deluge systems have both open and closed sprinklers. Make sure heat-responsive devices are provided in areas with both open and closed sprinklers and are in service. Fusing of a sprinkler will not operate a deluge valve. Where conditions permit, trip-test each deluge valve every 3 years by flowing water through the heads/nozzles. To conduct a deluge valve dry trip-test, do the following:

1. Close the main control valve.

2. Apply an electric heat lamp to at least one heat-actuating device in each circuit, testing one circuit at a time. Note the time required to trip the valve. Where flammable vapors may be present, use a hot cloth or hot water in place of the electric test set.

3. Reset the deluge valve and trip, using the manual release.

4. Where fixed temperature releases are involved, wait 15 minutes and trip by removing a fusible element from the tubing or a heat-responsive device.

5. When tests are complete, reset valves and open the main control valves.

Because there are so many designs of heat-responsive devices, test procedures for each cannot be included here. See the individual manufacturer's information for detailed testing procedure. During routine inspections, check for painted or corroded contacts, plugged vents, or painted domes. Clean or replace affected devices.

Cathodic Protection Equipment

Inspect cathodic protection equipment as follows:

1. While equipment is operating, note and record current flow shown by meters. If there is no current, check for blown fuses, electrodes touching the tank, ground-wire connection to tank, or electrodes not immersed in the water. If equipment operates at voltages or amperages over those listed on the nameplate, the rectifier may be damaged. Check polarity and direction of current flow. (If connections to rectifier are reversed, rapid damage to the tank occurs.)

2. Check condition of electrodes that deteriorate because of action of current passing from electrodes to water. Replace worn electrodes. (Watch for diminishing current flow on the ammeter; this is a sign that the electrodes may be failing.)

3. Protect electrodes from ice. If ice formation is a serious problem, turn off current and remove and store the electrodes during the freezing season. Tank protection will continue for about 3 weeks after the unit is out of operation. Reinstall the electrodes at the end of the freezing season.

Nonfreeze Systems

No special testing of nonfreeze systems is required, other than an annual check of the specific gravity of the nonfreeze solution. If the specific gravity indicates a need for replenishing the nonfreeze agent, be sure to add the same agent as was previously used.

High-Speed Suppression Systems

Full operational testing of high-speed suppression systems is conducted at intervals not to exceed 3 years except when mission requirements justify change. A detector or a manual release station must be actuated. Check to be certain that all nozzles are operating. Then, follow these steps to reset the system:

1. Replace pre-prime caps and/or rupture disks.
2. Refill piping with water.
3. If the system uses an explosive valve, replace the firing squib and the squib holder.

MAINTENANCE REQUIREMENTS

The need for maintenance is shown by periodic inspections. It should include replacement of worn or broken components and cleaning and flushing of systems. A regular schedule of maintenance requirements should be devised. Logs recording accomplished tasks should be maintained as a record of the system's history. Be sure to include manufacturers' manuals for the system components and consult them when making repairs and adjusting or troubleshooting the system.

GASEOUS EXTINGUISHING SYSTEMS

Gaseous extinguishing systems are generally found in areas where equipment is installed that would be highly vulnerable to destruction from water or dry chemical extinguishing agents. Computer rooms, electronic gear such as radio receiving and transmitting equipment, and power generating facilities are examples of areas where gaseous extinguishing system installation would

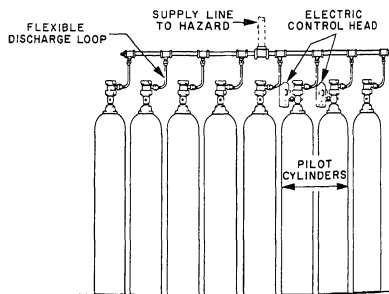
be desirable. In the Navy today, the Utilitiesman will come in contact with two commonly used systems. These are the carbon dioxide and the halogenated gas systems. Each of these systems is discussed in this section.

Gaseous extinguishing systems can be divided into three general categories: local application, total flooding, and hose line systems. *Local application systems* discharge agent onto the burning material and are commonly used for protection of paint dip tanks, restaurant range hoods, and special motors. *Total flooding systems* discharge agent into and fill enclosed space. They are commonly found in flammable liquid storage rooms, computer installations, and transformer vaults containing oil-filled equipment. *Hose line systems* discharge extinguishing agent through manually operated nozzles connected to a fixed supply by piping and/or hoses. At present, carbon dioxide is the only gaseous agent approved for manual hose line systems.

CARBON DIOXIDE SYSTEMS

Here are two general methods of applying carbon dioxide to extinguish a fire. One method creates an inert atmosphere in the enclosure or room where the fire is located for a prolonged period of time. This method is called *total flooding*. The second method is to discharge carbon dioxide to the surface of liquids or noncombustible surfaces coated with liquid flammables. This method is known as *local application*.

Carbon dioxide is electrically nonconductive. It is used extensively for the protection of



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Figure 8-30.—Typical cylinder arrangement for high-pressure CO₂ system.

electrical equipment. The nondamaging quality of this agent makes it useful as an extinguishing agent for computer rooms and computer tape vaults.

There are two general types of carbon dioxide extinguishing systems, high pressure and low pressure.

High-Pressure Systems

In the high-pressure system, high-pressure cylinders are used to store liquid carbon dioxide at ambient temperatures (fig. 8-30). Normal cylinder pressure is nominally 600 psi and varies with the ambient temperature of the storage area.

Storage area ambient temperatures should not exceed 130°F or be less than 32°F. For safety purposes, high-pressure cylinders have a frangible disk that will burst at 3,000 psi to prevent cylinder rupture as a result of overpressurization.

Low-Pressure Systems

Low-pressure systems have a pressure vessel maintained at 0°F by insulation and refrigeration equipment (fig. 8-31). At this temperature, the pressure in the container is approximately 300 psi. Because the container is kept at a low temperature, the container can be filled to 90 to 95 percent of capacity. For safety purposes a relief

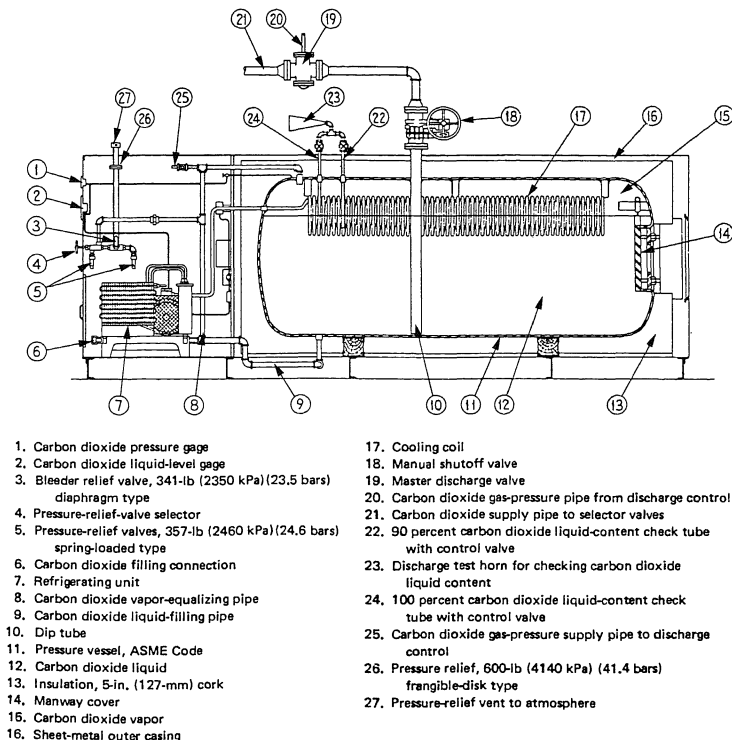


Figure 8-31.—Refrigerated low-pressure CO₂ storage tank.

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valve is installed to bleed off pressure at 341 psi. Another relief valve operates at 357 psi for rapid release of excess pressure. There is also a frangible disk designed to burst at 600 psi should the relief valves fail to control pressure buildups.

Advantages/Disadvantages of CO₂ Systems

There are advantages and disadvantages to each type of carbon dioxide system. Low-pressure storage units have a liquid level gauge that continuously monitors the amount of carbon dioxide in storage. High-pressure systems require weighing the cylinders. High-pressure systems permit storage of almost the exact amount of carbon dioxide required to protect a hazard area because of the flexibility and selection of cylinders in 50-, 75-, or 100-pound sizes. The smallest low pressure is 750 pounds. High-pressure systems require refilling and hydrostatic testing every 12 years. Low-pressure systems have no such requirement. Pressures in high-pressure systems vary with the ambient temperature; this affects the discharge rate of the system. Low-pressure systems keep the liquid carbon dioxide at 0°F and 300 psi at all times, assuring a uniform discharge rate. Another advantage of low-pressure systems is their ability to allow automatic, simultaneous discharge for more than one hazard area on an engineered basis. Hose reels can also be attached to these systems to operate simultaneously with hazard protection. A reserve supply can be provided by increasing the storage unit size of low-pressure systems. High-pressure systems require manifolding and valving arrangements to achieve a reserve supply.

Storage of the carbon dioxide is also a consideration in showing advantages or disadvantages of these systems. High-pressure systems require approximately 3 pounds of equipment for every pound of carbon dioxide stored. Low-pressure systems require less than 2 pounds for every stored pound. Usually, low-pressure systems require less floor space for storage of equal amounts of carbon dioxide as compared with high-pressure systems. In many instances, low-pressure storage containers may be placed outside of the buildings. High-pressure systems allow flexibility in space requirements since multiple cylinder banks may be stored in several smaller locations. Low-pressure systems require one large, single area for the refrigerated storage unit.

Operating Devices

As with all fire protection systems, carbon dioxide systems must have operating devices for discharge of the extinguishing agent and to cause

alarms to be actuated. Many of the operating devices discussed earlier in this chapter can be used. Most commonly used are the heat-actuated devices (H.A.D.) or smoke detecting devices. Manual controlling devices are also used in carbon dioxide systems. Whether the agent release is automatic or manual, an alarm at the alarm system control unit should be actuated.

Piping

Carbon dioxide fire protection system pipe and fittings are selected to have suitable low temperature characteristics and good corrosion resistance inside and out. Ferrous metals are galvanized. Steel, copper, brass, and other materials having similar mechanical and physical properties are acceptable. Copper tubing with suitable flared or brazed connections is also acceptable. Cast-iron (gray) pipe and fittings are not used.

Pipe and fittings for high-pressure systems have a minimum bursting pressure of 5,000 psi. In low-pressure systems, pipe and fittings have a minimum bursting pressure of 1,800 psi.

Between the storage tank and selector valves, black steel pipe may be used because of the larger sizes involved and its airtightness.

The supply piping is usually routed to prevent unnecessary exposure to high temperatures from ovens or furnaces or to direct flame impingement

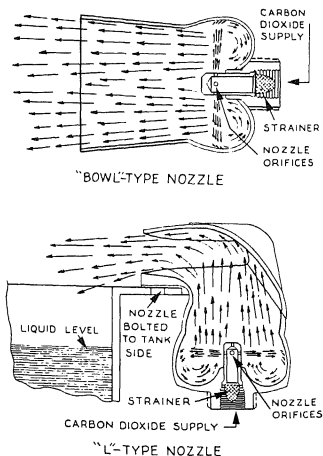


Figure 8-32.—Carbon dioxide nozzles.

before discharge. Hot piping causes excessive vaporization of carbon dioxide and a resultant delay in effective discharge.

Pressure relief devices or valves that prevent entrapment of liquid carbon dioxide may be installed on sections of piping that can be closed off. On high-pressure systems, relief devices usually operate at 2,400 to 3,000 psi, and, on low-pressure systems, at 450 psi.

Nozzles

Nozzles are of various designs and discharge patterns. Two common types are shown in figure 8-32. Nozzles are marked with a code number indicating the diameter in 1/32-inch increments of a single orifice standard nozzle having the same flow rate. A No. 5 nozzle, for example, has the same flow rate as a 5/32-inch-diameter standard orifice. A plus sign (+) after the number indicates a 1/64-inch larger size. Decimals are sometimes used to indicate sizes between the whole numbers.

TOTAL FLOODING SYSTEMS

Total flooding systems are used for rooms, ovens, enclosed machines, and other enclosed spaces containing materials extinguishable by carbon dioxide.

For effective total flooding, the space must be reasonably well enclosed. Openings must be arranged to close automatically and ventilation equipment to shut down automatically, no later than the start of the discharge. Otherwise, additional carbon dioxide must be provided to compensate for the leakage.

Automatic closing devices for openings must be able to overcome the discharge pressure of the carbon dioxide. Conveyors, flammable liquid pumps, and mixers associated with an operation may be arranged to shut down automatically on actuation of the protection system. A typical arrangement of a total flooding carbon dioxide system is shown in figure 8-33.

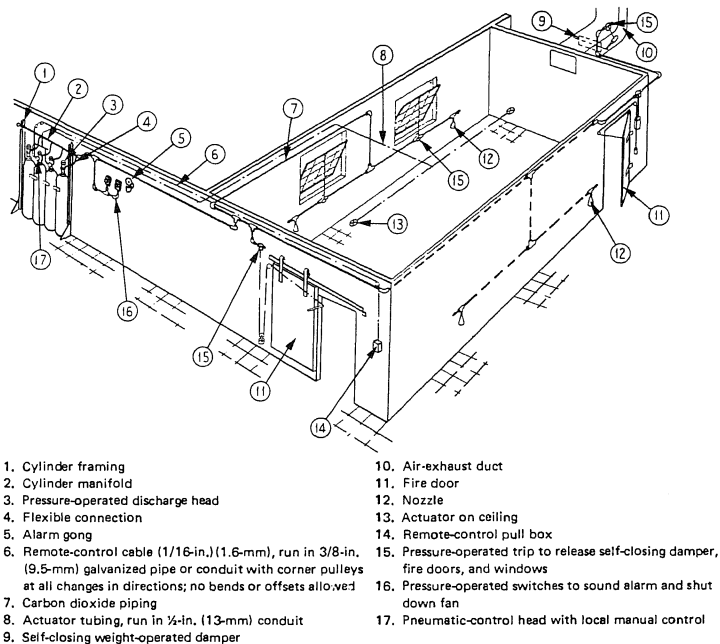


Figure 8-33.—Total flooding carbon dioxide system installation.

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LOCAL APPLICATION SYSTEMS

Local application systems are used to protect hazards such as oil-filled transformers and paint dip tanks. Ventilating fans, conveyors, flammable liquid pumps and mixers associated with the operation may be interlocked to automatically shut down when the protection system is activated.

A typical arrangement of a local application carbon dioxide system is shown in figure 8-34.

HOSE LINE SYSTEMS

Hose line systems are used to supplement fixed protection systems or portable fire extinguishers for all hazards extinguishable by carbon dioxide.

Hose line systems may be supplied either by high-pressure or low-pressure systems. A

high-pressure hose line installation is shown in figure 8-35.

HALOGENATED GAS SYSTEMS

Several types of halogenated gas systems have been developed for fire protection purposes: Halon 104, Halon 1001, Halon 1011, Halon 1202, Halon 1211, Halon 1301, and Halon 2402. The numbers relate to the chemical formulas of the gases. The first digit identifies the number of carbon atoms in the chemical molecule; the second digit identifies the number of fluorine atoms; the third digit identifies the number of chlorine atoms; the fourth digit identifies the number of bromine atoms; and a fifth digit, if any, identifies the number of iodine atoms present.

Primarily, Halon 1301 and Halon 1211 are in general use in the United States today. These

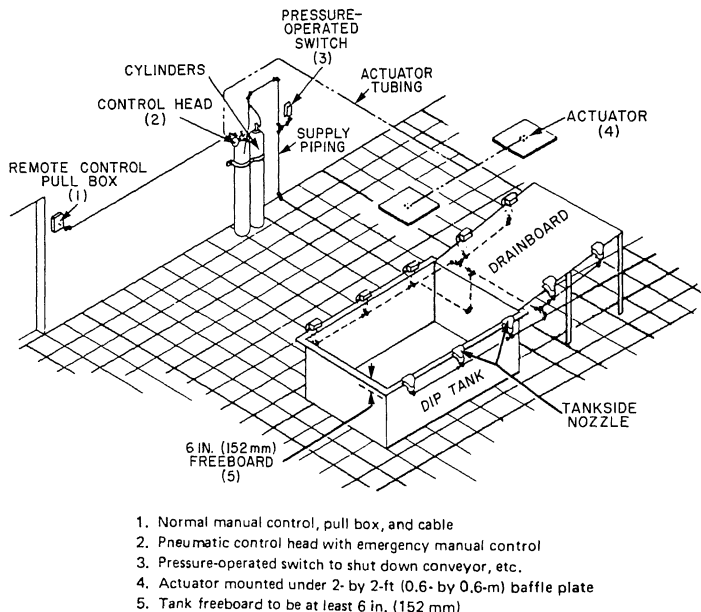
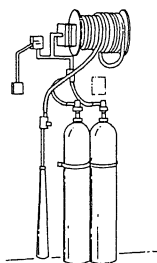


Figure 8-34.—Local application carbon dioxide system installation.

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Figure 8-35.—Carbon dioxide hose line system installation.

two types are recognized by the National Fire Protection Association (NFPA). Standards for their installation and use are published in the *National Fire Codes*.

Halogenated gas systems are usually used in the following situations:

- Where a clean extinguishing agent is needed
- Where energized electrical or electronic circuits are to be protected
- Where flammable liquids or flammable gases are present
- Where surface burning combustible solids are protected
- For high value objects or processes
- Where the area to be protected is normally occupied by people
- Where availability of water or space for other types of systems is limited

Generally, Halon 1211 and Halon 1301 are used in total flooding applications. At the present time there is no equipment approved for local application systems using halogenated agents.

For effective fire-fighting purposes, a minimum concentration of 5 percent is recommended for total flooding systems for surface fires of ordinary combustibles. Deep-seated fires, as

in cable insulation, require much larger concentrations and extended holding times.

Halon 1301 is the most commonly used halogenated gas in use today. It is the least toxic of any of the halogenated gases and does not harm personnel when concentrations are below 10 percent. (For additional information on Halon 1301, refer to NFPA Standard 12A.) The major use of Halon 1301 is in computer rooms.

Halon 1211 is toxic to people when concentrations exceed 4 percent. This prevents its use as a total flooding agent for areas occupied by personnel. (Halon 1211 is normally used in portable extinguishers because they do not allow a significant concentration to develop in a space to cause a hazard for people.)

Equipment for Halon fire extinguishing systems is similar to that used for high-pressure carbon dioxide systems. Halon 1301 is stored in a cylinder superpressurized with nitrogen to 600 psi (at 70°F) to provide an expellant pressure for the agent in excess of the agent's normal vapor pressure.

GASEOUS EXTINGUISHING SYSTEM ALARM SYSTEMS

There are some special considerations for alarm systems for gaseous systems because of possible toxic effects on personnel, the need for reasonably fast response, and reliable operation.

Response of gaseous extinguishing agents is not usually as urgent as foam agents, considering the types of hazards protected. Personnel safety from the possible toxic effects of the agents used also affects the speed requirement. Heat and/or smoke detectors are frequently used as initiating devices.

Cross-zoning is also frequently used for gaseous extinguishing systems. The first detector (zone) actuation is usually arranged to cause a local audible and/or visual signal. The second detector (zone) actuation causes a distinctive local signal to warn personnel that the extinguishing agent is about to be released.

Some gaseous extinguishing systems, usually those protecting populated spaces, have an abort feature to avoid unnecessary discharge of an expensive, possibly toxic gaseous agent. Extinguishing systems with the abort feature have a time delay between actuation of the second (or only) detector and release of the agent. The delay may be factory set or adjustable. It is usually set in the range of 15 to 60 seconds to allow time for personnel to leave the area before release of the

agent and to allow for manual interruption of the agent release sequence. If the situation is not dangerous, the sequence can be interrupted by a manual abort switch. When the detectors and control unit have been restored to their normal condition, the abort switch can be restored. The abort switch is usually designed to be held in (until the control panel is reset) so that the agent discharge cannot be accidentally impaired when the switch is unattended.

Initiating Devices

Frequently used detectors for gaseous agents are spot-type ionization smoke detectors and rate-compensated heat detectors. Factors affecting detector effectiveness, such as electrical power and air pressure, if pertinent, are supervised.

One or two manual methods for release of the gaseous agent are usually provided.

- Manual fire alarm devices are frequently connected to the alarm system control unit to cause immediate discharge of the gaseous agent, regardless of cross-zoning and time delays otherwise provided.

- Manual devices may also be connected electrically to cause direct release of the agent, independent of the alarm system.

- Direct mechanical release of agent may be by manual actuation of a control valve.

Whether the agent release is caused by an alarm control unit auxiliary output or by an independent manual method, there should be an alarm at the alarm system control unit. Manual release of the gaseous agent usually causes an alarm by actuating a pressure switch that senses the increase in pressure in the gas line or manifold between the release valve(s) and the nozzles.

Sequence of Alarms

The normal circuit arrangement for a building alarm system to release a gaseous extinguishing agent is the same as for a building system with added features such as cross-zoning, the abort feature, manual release of agent, and other specific auxiliary functions of the alarm system. Alarm systems that release a gaseous extinguishing agent use auxiliary alarm outputs to segregate the protected area and reduce dispersion and dilution of the agent. Typical auxiliary functions are fan

shutdown, door (and window) closure, and closure of air-handling system dampers. Gaseous agent-releasing alarm systems applied to computer room installations also shut down computer power at the time the agent is released to eliminate the heat source for possible electrical fires.

A typical sequence of alarm system-initiated events in a computer room installation that includes all the usual features is as follows:

- Detection of fire by first detector in an area causes local and remote alarm indication, fan shutdown, door and damper closure, and other miscellaneous auxiliary functions through interlocks with building systems.

- Detection of fire by second detector in the area (cross-zoned with first detector) causes a distinctive local audible signal and initiates a time delay during which agent release and computer power shutdown may be aborted.

- At the end of an adjustable delay (normally 20 seconds), assuming the release is not aborted, computer power is shut down and the extinguishing agent is released into the protected area.

INSPECTION, TESTING, AND MAINTENANCE OF GASEOUS SYSTEMS

Inspection, testing, and maintenance of gaseous fire extinguishing systems are required to be sure they are in proper operating order. Inspection and test frequencies for these systems are summarized in table 8-4.

Carbon Dioxide High-Pressure Systems

Check hoses and nozzles, cylinders, and cylinder pressure as follows:

Weekly, check that all nozzles and hand hose lines are clear and in the proper position and that all operating controls are properly set.

Semiannually, weigh cylinders and replace any that show a weight loss of greater than 10 percent. To weigh cylinders, do the following:

- Loosen each cylinder support and disconnect each discharge head. Discharge heads are designed to be removed and replaced without tools.

Table 8-4.—Summary of Inspection and Test Frequencies for Gaseous Systems

	WEEKLY	MONTHLY	SEMI-ANNUALLY	ANNUALLY
Check CO ₂ and Halon nozzles and hand hose lines	X			
Weigh cylinders			X	
Check liquid level in low-pressure CO ₂ storage tanks	X			
Check devices and connections of low-pressure CO ₂ systems for leakage		X		
Test tank alarm pressure switch and identification device			X	
Conduct actuating and operating tests of CO ₂ and Halon system cylinders				X
Hydrostatic test of cylinders and hoses	(See text for frequency)			

● Weigh cylinders with a beam scale or with a platform scale. To weigh with a platform scale, remove the cylinders completely from the rack and lift them on to the scale.

Test cylinders and hoses hydrostatically as follows:

Hydrostatically test cylinders to a minimum pressure of 3,000 psi. The frequency for testing is as follows:

● If discharged after 5 years from date of last test, perform hydrostatic test.

● If not discharged after 12 years from date of last test, discharge cylinder and perform hydrostatic test.

Hydrostatically test hoses to a minimum pressure of 1,250 psi. The frequency of testing is the same as for cylinders.

Carbon Dioxide Low-Pressure Systems

Check nozzles, pressure and level gauges, and for leaks in all devices.

Weekly, check to see that all nozzles are clear and in the proper position and that all operating controls are properly set. Check and record the

reading on the liquid level gauge of all storage tanks. Refill tanks when the quantity is less than the minimum required to protect the largest single hazard, including any required reserve supply.

Monthly, check for leaks on all devices and connections under continuous pressure, including valve packing glands, screwed connections, and safety relief valves.

Semiannually, test the tank-alarm pressure switch and the operation of the alarm bell or light by reducing and increasing the pressure. Perform this test as follows:

● Close valve on the piping from the vapor space to the alarm pressure switch.

● Remove the test plug to reduce pressure.

● Increase pressure by connecting a high-pressure cylinder to the test opening.

● After testing, disconnect the high-pressure cylinder, replace the test plug, and reopen the valve on the alarm pressure switch piping.

● If the bell or light fails to operate on the pressure test, repair or replace, and test again.

Check the liquid level and pressure gauges for accuracy once each year.

Replace frangible disks on the storage tanks once every 5 years.

Maintain refrigeration equipment according to the manufacturer's instructions.

Halogenated Systems

Follow these procedures to test halogenated systems.

Weekly, check to see that all nozzles are clear and in proper position and that all operating controls are properly set.

Semiannually, check weight and pressure containers. (See procedures for verifying CO₂ cylinders.)

- If the container has a loss in net weight of more than 5 percent or a loss in pressure (after adjusting for temperature) of more than 10 percent, either refill or replace the container.
- If a factory-charged nonrefillable container that does not have a pressure indicator shows a loss in net weight of more than 5 percent, replace the container.

Annually, test all actuating and operating devices. A cylinder containing carbon dioxide or refrigerant may be used in place of Halon cylinders to minimize the cost of a discharge test, or a simulated test of pressure-operated devices may be conducted.

Alarm Systems

Tests and maintenance of detectors, circuits, control units, annunciators, relays, and power supplies are as described in chapter 3 of NAVFAC MO-117, *Maintenance of Fire Protection Systems*. Some additional steps are required to test cross-zoned detectors, electrically operated releases for gaseous agents, and the abort feature.

Release Devices and Auxiliary Functions

Test electrically operated release devices for gaseous extinguishing systems annually. Combine the test with tests of detectors and the total alarm system. If an actual discharge test is not desired, be sure to prevent gas discharge and computer power shutdown, if provided, while allowing observation of electrical functions. This may require valve closure or partial disassembly of diaphragm-piercing, solenoid plunger-type valves and manual override of the computer shutdown feature. Refer to system instructions from the equipment manufacturer or installing company. The same method,

once determined, is normally used for testing manual devices electrically connected to cause direct actuation of gas release devices.

After taking necessary steps to prevent gaseous discharge, cause the necessary alarm conditions to actuate the extinguishing system by actuating detectors or manual initiating devices. At the end of the time delay interval, release device actuation should be evident by sound or visual observation. Verify that relays for auxiliary functions actuate. Take notes on which event relays are actuated at the first cross-zoned detector alarm, second cross-zoned detector alarm, and at the end of the timer interval. Note the amount of time delay between the second detector actuation and the delayed functions.

If release devices or auxiliary functions fail, check appropriate output voltages at the control unit and at the failed device with the control unit in the alarm condition. If voltages are improper, troubleshoot the control unit or circuit as indicated. Cross-zoned systems require an alarm condition on both initiating circuits in an area to actuate release devices and some auxiliary functions. If a timed function fails, check input voltage to the timer and the delayed output voltage from the timer with a voltmeter. Replace the timer if input is proper but output is not.

If voltages are proper, check solenoid and relay coil continuities with one side of their respective energizing circuits open to the control unit. See testing and maintenance for foam systems, section 7.3.1 of NAVFAC MO-117, *Maintenance of Fire Protection Systems*, for instructions for this test. Replace defective devices and/or wiring.

Abort Feature

In gaseous extinguishing systems with an abort feature, test the feature annually, along with the other elements of the system. To test the abort feature, first determine the timer setting from prior test records or installation data. Then, cause first and second cross-zoned detector alarms. The second detector alarm starts the timed period during which the gaseous agent release and other abortable functions may be activated. Operate the abort switch approximately in the middle of the time interval. The test should normally be performed with agent release and computer shutdown features disabled. At the end of the time interval, confirm that the aborted functions do not occur.

Possible causes of abort failure are:

- a defective abort switch,

● a defect in the wiring between the abort switch and the main control unit, or

● an improper abort feature installation or an improper timer setting (low).

During troubleshooting, disable the extinguishing agent release and the computer shutdown feature, if provided. Check the abort timer setting according to the manufacturer's instructions. If the timer setting is quite low, 15 seconds or less, increase the setting to 20 seconds or more (as determined by local authorities to be adequate to prevent unnecessary discharge of the agent).

If actuating the abort switch has no effect, check the switch continuity with an ohmmeter while actuating it disconnected from its wiring. If the switch continuity shows alternating readings of zero ohms and infinite resistance, as it should when being repeatedly actuated, check that the OFF and ON positions of the switch are not reversed. (Such reversal may be caused by connecting the wires to the wrong pair of switch

terminals or inverting the switch when mounting it.) If the switch has no defect, check its circuit continuity with an ohmmeter at the control unit and with at least one wire disconnected from the control unit. Observe switch action at the ohmmeter by actuating the switch repeatedly. Correct any circuit defects or wiring errors. Replace the switch if it is defective.

DRY CHEMICAL EXTINGUISHING SYSTEMS

Dry chemical extinguishing systems are very similar in construction and operation to gaseous extinguishing systems. There are three general categories of chemical extinguishing systems: total flooding, local application, and hose line systems.

Total flooding systems are arranged to discharge the agent into enclosed spaces. Such systems are used for the protection of flammable liquid storage rooms and paint drying ovens (fig. 8-36). Ventilating equipment, conveyors,

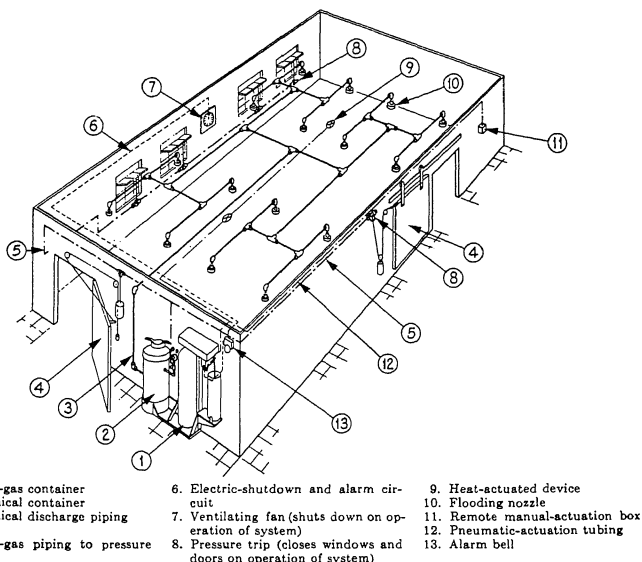


Figure 8-36.—Total flooding dry chemical system installation.

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flammable liquid pumps, and mixers may be interlocked with the dry chemical system and arranged to shut down automatically upon discharge of the system.

Local application systems are arranged to discharge dry chemical directly on the hazard, without any enclosure (fig. 8-37). Typical local application systems are used for the protection of paint dip tanks and restaurant range hoods. Ventilating fans, conveyors, flammable liquid pumps, and mixers may be interlocked to shut down automatically upon discharge of the system.

Hose line systems discharge dry chemical through manually operated nozzles connected by hose or by piping and hose to a fixed supply (fig. 8-38).

Dry chemical used in approved systems is mostly sodium bicarbonate, very finely ground, to which has been added other ingredients to keep it free flowing and to resist caking. Other agents used in dry chemical extinguishing systems include potassium bicarbonate, potassium chloride, and monoammonium phosphate—multipurpose type.

The dangers dry chemicals used in fire extinguishing concentrations cause exposed personnel are temporary breathing difficulty and reduced visibility. In areas using total flooding systems, suitable means should be provided to permit evacuation of personnel. In areas using local application systems where the dry chemical is not confined, there is little hazard to personnel.

Dry chemical systems are used primarily for extinguishing fires in flammable liquids. Bicarbonate base dry chemical can be particularly effective for extinguishing fire in deep fat fryers caused by overheating. The *saponification* reaction between the dry chemical and fat or grease

prevents re-ignition by turning the fat to soap. Multipurpose dry chemical will not react with the fat or grease and can prevent the saponification reaction between the fat or grease and any bicarbonate base dry chemical subsequently used.

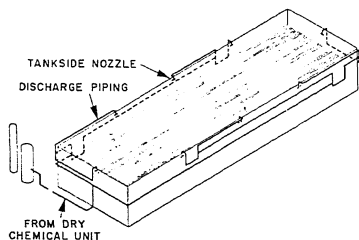
Dry chemical systems are not suitable for fires in materials (such as cellulose nitrate) that contain their own oxygen supply. They are not normally used for fires involving delicate electrical equipment such as telephone switchboards, computers, and certain other electronic equipment because the dry chemical will insulate the fine and delicate contacts. The contacts will then need complete cleaning.

Monoammonium phosphate and potassium chloride are slightly acidic, and in the presence of moisture can corrode metals such as steel, cast iron, aluminum bronze, and titanium. Corrosion can be minimized by prompt cleanup. Most dry chemical agents can be cleaned up by wiping, vacuuming, or washing the exposed materials or surfaces. Monoammonium phosphate will require some scraping and washing if exposed surfaces were hot when the agent was applied.

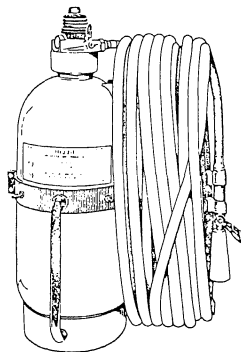
TYPES OF SYSTEMS

There are basically two types of dry chemical systems.

1. Gas cartridge systems that use a container of expellant gas that, when released by manual



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Figure 8-37.—Local application dry chemical system installation.



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Figure 8-38.—Stored pressure dry chemical cylinder with hose line.

or automatic means, pressurizes the container of dry chemical and forces the agent through the piping network or hose lines (fig. 8-39).

2. Stored pressure systems that consist of a container of dry chemicals that is constantly pressurized, usually with nitrogen.

SYSTEM COMPONENTS

Operating devices are used to release the expellant gas from its container for the pressurization of the dry chemical tank or to release the dry chemical if it is normally stored under pressure.

In fixed systems, expellant gas is released from its container by electrically, pneumatically, or mechanically dropping a weight that opens a cylinder valve or by mechanically releasing a spring that punctures the sealing disk of a gas cartridge. The dry chemical when stored under pressure is released by pneumatically or mechanically dropping a weight that opens the discharge valve.

Pressure trips may be used to release the weights of more than one unit for simultaneous discharge on hazards needing a greater capacity than is available for one unit. Pressure trips are operated by gas pressure taken from the low-pressure side of the expellant gas regulator.

Hose line systems are actuated at the cylinder by turning a handwheel or by moving a lever.

The *distribution system* (piping) should be constructed of standard weight (schedule 40)

galvanized steel pipe and standard weight galvanized steel or malleable iron fittings.

It is important that the piping system be balanced so that the pressure drop to any one nozzle will be about the same as to any other nozzle. Although dry chemical suspended in a gas may be homogeneous during flow, resembling a liquid, certain effects such as inertia and sudden expansion of the gas may cause some separation of the two phases.

For example, if several nozzles were installed consecutively at right angles to a straight run of pipe, the inertia of the dry chemical would carry most of it past the first nozzles. These nozzles would, therefore, discharge more gas and less dry chemical than those farther down the piping system. To eliminate this, all branch piping is balanced by the use of tees (the dry chemical entering the side port and leaving through the two end ports).

Nozzles are of various designs and discharge patterns. Nozzles used for distributing the dry chemical are of a type approved for the particular application.

CHAPTER REFERENCES

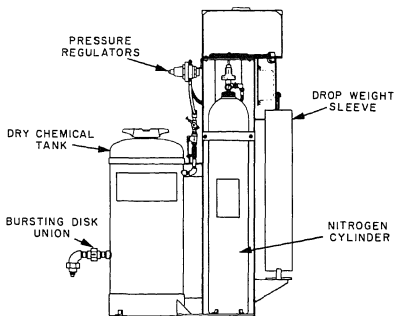
Carbon Dioxide Extinguishing Systems, NFPA 12, National Fire Protection Association, Battery March Park, Quincy, Mass. 02269, November 1980.

Deluge Foam-Water Sprinkler and Spray Systems, NFPA 16, National Fire Protection Association, Battery March Park, Quincy, Mass. 02269, November 1980.

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Figure 8-39.—Dry chemical and expellant gas storage cylinders with piping connection.

CHAPTER 9

WATER TREATMENT AND PURIFICATION

Learning Objective: Analyze the theories of operation of equipment required for treatment and purification of water, noting the considerations taken when choosing, operating, maintaining, and supervising the installation of water treatment equipment and sources.

As a Utilitiesman, you will be responsible for ensuring that an adequate supply of safe water is available for domestic and fire protection uses. In meeting this responsibility there are several factors you must consider. They are the selection of a water source, how to develop the water source, what contaminants you will encounter, and the selection of methods you will use to remove these contaminants. This chapter discusses each of these considerations.

WATER SOURCE SELECTION

The first consideration you will encounter is the selection of a water source. Three factors must be considered in this selection: water source quantity, quality, and reliability.

SOURCE QUANTITY

Water sources developed for military use are commonly referred to as water points. Water points are classified as follows:

1. Surface water (streams, lakes, and rivers)
2. Ground water (wells and springs)
3. Seawater
4. Rain, snow, and ice

When selecting a water source, you must consider how much water is available and how much water will be demanded for use. Before dealing with demand, let's discuss how much water is available at the source.

The amount of water that may collect in any surface source will depend on the amount of precipitation, the size of the drained area, geology, ground surface, evaporation, temperature, topography, and artificial controls.

The available water at a source can be estimated by using some simple calculations. To calculate the quantity of water (gallons per minute) flowing in a stream use the following formula:

$$Q = 6.4 \times A \times V$$

Q = Quantity of water in gallons per minute (gpm)

6.4 = A constant—There are 7.5 gallons of water per cubic foot. However, because of error in stream measurement, 7.5 has been reduced to 6.4.

A = The area of the stream in square feet obtained by multiplying the width times the average depth of the stream.

V = The velocity of the stream in feet per minute obtained by measuring the time it takes a floating object to travel a known distance.

An example of this calculation would be a stream having an average depth of 2 feet and a width of 16 feet, and a twig is noted to flow 13.3 feet per minute. To find the amount of water flowing in the stream, you would work the equation as follows:

$$Q = 6.4 \times A \times V$$

$$Q = 6.4 \times (2 \times 16) \times 13.3$$

$$Q = 6.4 \times 32 \times 13.3$$

$$Q = 2,723.84 \text{ gpm}$$

To calculate the quantity of water in a lake or pond having little or no runoff, multiply the

surface area by the average depth. The answer will be in cubic feet. Multiply by 7.5 to get the gallons in the water source.

An example of this would be a pond with an average depth of 7 feet and a surface area of 2,864 square feet. It would be calculated as shown below:

$$Q = A \times D \times 7.5$$

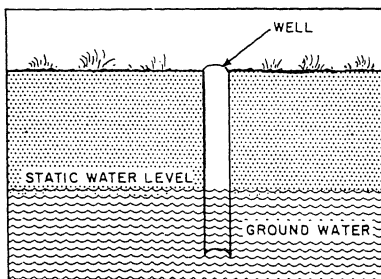
$$Q = 2,864 \times 7 \times 7.5$$

$$Q = 1,052,520 \text{ gallons}$$

Lakes and ponds are usually located within the water table and the hydraulics of the water feeding the lake or ponds may be similar to that of wells. Therefore, a drawdown test, using a method similar to the one described below for wells, may be used to calculate the quantity of water. The test should consist of the drawdown of the static water level 1 or 2 feet and the recovery time recorded. A method must be devised to discharge the water being pumped in such a manner that it does not return to the source during the test.

To calculate the quantity of water that may be supplied from newly constructed or existing wells, a drawdown test must be made. For this test to be performed properly, the hydraulics of a well must be understood.

Before being pumped, the level of water in a well is the same as the level of the water table in the water-bearing formation in which the well is completed. This is called the static level in the well and in the foundation. See figure 9-1. The depth from the ground surface to the static water level is measured, and this distance is used to describe its position. Thus, if the water in the well



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Figure 9-1.—Static water level before pumping.

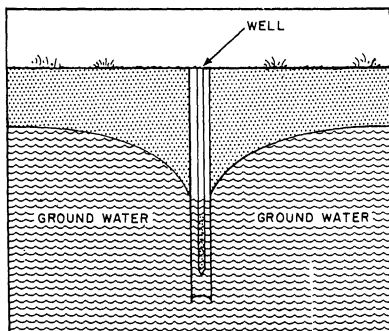
is 25 feet below ground, the static water level is said to be 25 feet for this well. Elevation of the static water level above mean sea level can also be used to describe its position.

When a well is pumped, the water level drops. After several hours of pumping at a constant rate, it stabilizes itself in a lower position. This is called the pumping level or dynamic water level for this rate of pumping. See figure 9-2.

The distance that the water is lowered by pumping is called the drawdown. It is the difference between the static level and the pumping level. The drawdown in the well, resulting from pumping, lowers the water pressure in the well, but the surrounding water-bearing formation retains its original pressure. In response to this difference in pressure, water flows out of the pores of the formation into the well.

The water-bearing formation does not give up its water all at once to the pumped well. The flow of water into the well is held back by the frictional resistance offered by the formation to the flow of water through its pores. The resistance varies in each formation and is developed in direct proportion to the rate of movement or velocity of the water in the formation. It follows from this that the rate of flow resulting from a given pressure difference depends on the frictional resistance to flow developed in the formation. The term used to describe this characteristic of a porous material is *permeability*.

For a particular type of well to be constructed, the yield of the well for any given drawdown is



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Figure 9-2.—Pumping level.

directly proportional to the permeability of the formation. This property of the formation varies through wide ranges, the value for a coarse sand stratum being several hundred times that of a fine sand stratum of the same thickness. It increases with the coarseness of the sand and decreases with the compactness of the material. It increases where the sand grains are more nearly uniform in size. It decreases when fine sand and silt fill the voids between larger particles. The permeability of a rock formation, like limestone, varies with the number and sizes of the fractures, crevices, and solution channels.

The measurements that should be made in testing wells include the volume of water pumped per minute or per hour, the depth to the static water level before pumping is started, the depth to the pumping level at one or more constant rates of pumpage, the recovery of the water level after pumping is stopped, and the length of time the well is pumped at each rate during the testing procedure. The testing described in this chapter is essentially the measurement of the hydraulic characteristics of a particular well.

The pump and power unit used for testing a well should be capable of continuous operation at a constant and variable rate of pumpage for a period of over 24 hours. It is important that the

equipment be in good condition for an accurate test, since it is undesirable to have a forced shutdown during the test. The test pump should be large enough to test to the expected capacity of the well, even though this may be far beyond the amount of water required and may exceed the capacity of the permanent well pump. Pumping by airlift may be a practical method, provided that meters are not used for measuring the flow. The test should run at least 24 hours. Longer tests, up to several weeks' duration, may be desirable to verify adequacy of the formation.

To determine the safe yield of the well, the pump should be operated at a rate that will cause only about 50 percent of the maximum possible drawdown. The drawdown should not exceed a point 5 feet above the topmost screen slot. For example, a 125-foot well has a static water level of 25 feet and a pumping level of 75 feet or a 50-foot drawdown. The satisfactory pumping level is 50 feet or 50 percent of the maximum drawdown. Therefore, a safe well capacity is established and maintained for that condition regardless of the yield. The safe pumping yield is the withdrawal rate that will not cause a lowering of the water table, and should cause no more than 50 percent of maximum drawdown. A chart, similar to the one shown in figure 9-3, should be

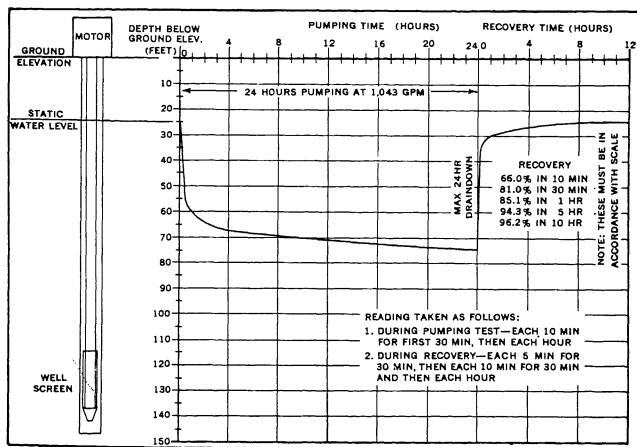


Figure 9-3.—Well chart.

included in the test report. The complete test report will include the following:

1. Initial static water level
2. Pumping rates, at least every hour
3. Drawdown data, at least every hour
4. Rate of recovery

The simplest way to measure the water pumped is to catch it in a steel drum or other tank of known volume. The time required to fill the tank is determined as accurately as possible. The rate of pumpage in gallons per minute is then calculated. For reasonable accuracy, the tank should be large enough to hold the water pumped during a period of at least 2 minutes. This limitation makes the method practical only for relatively small wells, since large tanks will not usually be available.

Water meters offer a definite advantage in measuring the water being pumped. The amount of water pumped may be recorded from the meter at desired intervals. The total discharge may be recorded for any individual phase of the draw-down test.

The most accurate way to measure depth to the static level and to the pumping level in a well is with a chalked tape. A steel tape with a weight to make it hang straight is chalked at the lower end with blue carpenter's chalk and lowered into the well until 1 or 2 feet of the tape is submerged. The proper length to lower the tape may have to be determined by experiment. The wetted length of the tape shows up very clearly on the chalked portion of the tape. This length is subtracted from the total length lowered below the reference point; this gives the depth to water.

The drawdown observed during a well test is the difference in feet between the

Table 9-1.—Daily Water Requirements in Temperate Zone

Unit consumer	Conditions of use	Gallons per unit consumer per day	Remarks
Man	In combat:		
	Minimum	½ - 1	For periods, not exceeding 3 days, when operational rations are used.
		2	When field rations are used.
	Normal	3	Drinking plus small amount for cooking or personal hygiene.
	March or bivouac	2	Minimum for all purposes.
	Temporary camp	5	Desirable for all purposes (does not include bathing).
	Temporary camp with bathing facilities	15.	
Vehicle	Semipermanent camp.	30 - 60	Includes allowance for waterborne sewage system.
	Permanent camp	60 - 100.	
	Level and rolling country.	1/8 to 1/2	Depending on size of vehicle.
Hospital	Mountainous country	1/4 to 1	Depending on size of vehicle.
	Drinking and cooking.	10 per bed	Minimum, does not include bathing or water for flushing.
	With waterborne sewage.	50 per bed	

pumping level and the static water level before pumping was started. The specific capacity of the well is the yield or discharge in gallons per minute divided by the drawdown in feet.

Water needs should be estimated, using per capita requirements and other controlling demands as factors in arriving at the estimate. Other controlling demands may be the water requirements for such items as fire protection, industrial uses, lawn sprinkling, construction, leakage, and water delivered to other activities, and vehicles. Table 9-1 shows the per capita daily water requirements for different situations, and the daily average requirements for vehicles. Table 9-2 indicates the requirements that may be needed for construction equipment. Compare the yield of the source with the needs of the activity.

SOURCE QUALITY

The quality of water is the ability of water to be potable and palatable (water that is safe to drink, being free of harmful characteristics that could cause odor, foul taste, bad color and/or disease).

Practically all water supplies have been exposed to pollution of some kind. The general growth of population and the increasing use of streams and other bodies of surface water for the disposal of wastes have been detrimental to water sources.

Impurities in water are either suspended or dissolved. The suspended impurities are usually more dangerous to health. They include mineral matter, disease organisms, silt, bacteria, and algae. These must be destroyed or removed from water that is to be consumed. While some of these impurities can be seen by the naked eye, others

Table 9-2.—Quantity and Quality of Water Needed by Construction Equipment

Equipment	Size	Quantity	Purity of water
Rock crusher	225-T	60,000 gpd	No special purification. Seawater usable.
Concrete mixers		18,000 gpd	Potable; minimum of organic matter. Acid alkali free. Seawater may be used but decreases concrete strength by 20%. Extra cement may be used to offset this effect.
Concrete paver		60,000 gpd	Alkali free. Low sulfates.
Asphalt plant		1,000 gph	Potable; low calcium and magnesium.
Steam jenny			" " " "
Steam boiler	200-hp.	2,000 gpd	" " " "
	w/receiver	1,000 gpd	" " " "
Three car heater (for asphalt plants)		50 gph	" " " "
Water distributor	1,000 gal	1,000 gal per 100 yd of 8 ft road.	No special purification. Salt water acceptable.
Compaction		Variable	Any available water accepted. Seawater actually preferable for certain jobs.
Vehicle radiators		Variable	Potable; calcium and magnesium lower than 400 ppm.
Asphalt rollers		Variable	Potable; free of organic matter.

cannot, but can be detected by taste or odor. Still others can be detected by laboratory tests only. Table 9-3 identifies some of the common impurities in water and summarizes their effect on water quality. Some water tests may be made in the field; these are covered in *Utilitiesman 3 & 2*, NAVEDTRA 10660.

Water samples will have to be forwarded to a laboratory for complete mineral or bacteriological analysis. The method for gathering these water samples is also included in *Utilitiesman 3 & 2*.

The factors that affect and determine the quality of water, such as physical, chemical, biological, and radiological contamination, will be discussed later in this chapter.

SOURCE RELIABILITY

The reliability of a water supply is one of the most important factors to be considered in the selection of a water source. The information gathered during the water reconnaissance may indicate a source of sufficient supply, only to have the source dry up during periods of little rainfall. Therefore, hydrological data should be studied to determine the variation that may be expected at the water source.

Geological formations greatly influence the reliability of a ground water source. The amount of water flowing and the rate of flow may be controlled by geological layers. The amount of water within the water table may be limited by impervious formations, as shown in figure 9-4. Therefore, it is important that information on the characteristics and properties of the geological

Table 9-3.—Common Impurities in Water

Suspended impurities	Organisms.		Some cause disease.	
	Algae		Cause taste, odor, color, turbidity.	
	Suspended solids		Cause murkiness or turbidity.	
Dissolved impurities	Salts	Calcium and magnesium.	Bicarbonate	Causes alkalinity, hardness.
			Carbonate	Causes alkalinity hardness.
			Sulfate	Causes hardness.
			Chloride	Causes hardness, corrosive to boilers.
		Sodium	Bicarbonate	Causes alkalinity.
			Carbonate	" "
			Sulfate	Causes foaming in steam boilers.
			Fluoride	Causes mottled enamel of teeth.
			Chloride	Causes salty taste.
	Iron	.....	Causes taste, red water, incrustation on metals.	
	Manganese	.....	Causes black or brown water.	
	Vegetable dye	.....	Causes color, acidity.	
	Gases	Oxygen	Causes corrosion of metals.	
		Carbon dioxide	Causes acidity, corrosion of metals.	
		Hydrogen sulfide	Causes odor, acidity, corrosion of metals.	
		Nitrogen.	No effect.	

formations be studied when a ground source is being considered.

It may be necessary to consider numerous other factors that may affect the reliability of the source. For one example; Lake Bonnie Rose, U.S. Naval Station, Adak, Alaska, is an ample source of cool, clear water, being distributed by gravity. However, the relatively high elevation of the lake results in excessive pressure at the station. Pressures are controlled by pressure-reducing valves. The valves sometimes fail in service, resulting in damage to the water system.

Reliability of the source is further increased as the requirements for items that are subject to breakdown decrease (pumps, treatment plants, and so on).

Legal advice may be necessary when selecting a water source as the laws regulating and controlling water rights may vary considerably. The title to ground and surface water in the United States is usually regulated at the state level. Navigable waters having interstate traffic are under federal control. Some difficulty was experienced in Vietnam by SEABEES in securing water rights to surface streams. These waters were used for flooding of rice fields, and local control denied the use of these sources as water supplies.

Legal advice may also be required in securing the right for waterlines or powerlines to cross property. To cite one example, a waterline serving a naval air facility in Sicily was completed, except for a section crossing an irrigation ditch. Final completion of the waterline was delayed for

2 months, waiting to obtain the right for the waterline to cross the ditch.

DEVELOPMENT OF WATER SOURCES

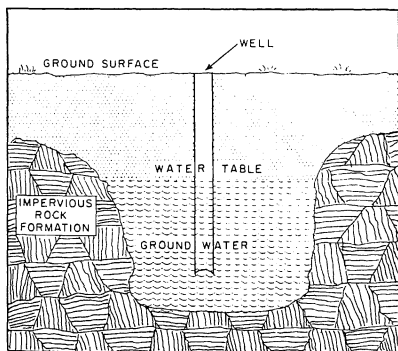
Development of a water source includes all work that increases the quantity and improves the quality of the water, or makes it more readily available for treatment and distribution. The development of surface water sources, springs, and seawater sources is considered in this section.

In developing a source, dams, floats, galleries, and similar improvements may be used to increase the quantity and quality of the water. Elaborate developments should be avoided; simplicity brings more rapid results. A temporary water source should not be converted into a permanent one until the area has been reconnoitered for a source requiring less development. All intake hoses or pipes should be equipped with an intake strainer regardless of the clearness of the water source. Suction strainers should be protected from floating debris that may damage, clog, or unnecessarily pollute them. Proper anchorage of suction lines and strainers prevents (1) loss of prime, (2) punctured or kinked lines, and (3) damage to strainers. Water at the intake point should be as clear and deep as possible. The strainer on the suction hose is placed at least 4 inches below the water level. This precaution reduces the possibility of the strainer becoming clogged with floating debris, or the prime being lost because of air getting into the suction line.

SURFACE WATER DEVELOPMENT

Of the total amount of rainwater that falls upon the land surface of the earth, only a comparatively small part is absorbed by the soil. By far the greater part of it runs off the surface of the ground and is carried out to the sea by way of streams and rivers or remains stored in natural lakes and ponds and in artificial lakes and impounded reservoirs. The methods by which water supply is derived from the surface are (1) by damming of streams or rivers, (2) by using the flow from streams, (3) by pumping directly from surface streams, (4) by collecting water from the roofs of buildings, (5) by providing catchment areas for the collection of rainwater into specially constructed cisterns, (6) by solar distillation, (7) by power distillations, (8) by freezing, and (9) by electrodistillation.

For normal field water supply, surface water is the most accessible type of water source. This

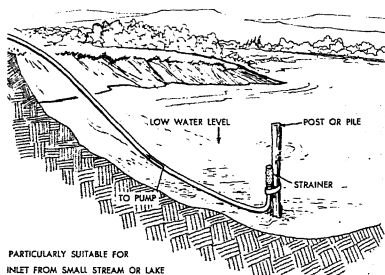


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Figure 9-4.—Limitation of water by rock formation.

source also lends itself readily to the purification equipment common to most engineer units. Surface water is the most easily developed source of water. Methods of constructing intake points for land surface water sources are discussed below.

If the stream is not too swift and the water is sufficiently deep, an intake may be prepared quickly by placing the intake strainer on a rock. This will prevent clogging of the strainer by the streambed and provide enough water overhead to prevent the suction of air into the intake pipe. If the water source is a small stream or shallow lake,



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Figure 9-5.—Direct intake with hose on bottom of water source.

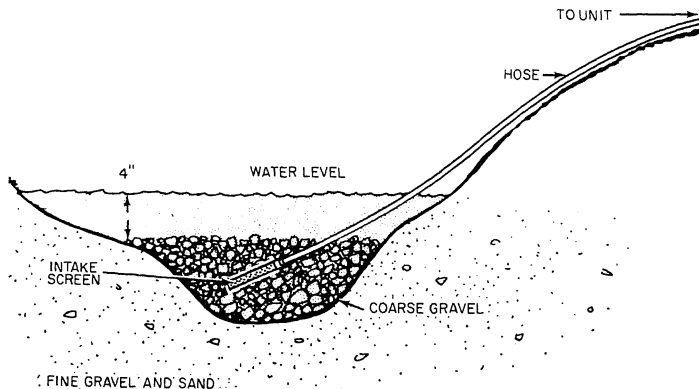
the intake pipe can be secured to a post or pile as shown in figure 9-5.

When a stream is so shallow that the intake screen is not covered by at least 4 inches of water, a pit should be dug and the screen laid on a rock or board placed at the bottom of the pit. Pits dug in streams with clay or silt bottoms should be lined with gravel to prevent dirt from entering the purification equipment (fig. 9-6). The screen is surrounded by gravel to prevent collapse of the sides of the pit and also shield the screen from damage by large floating objects. The gravel also acts as a coarse strainer for the water. A similar method may be provided by enclosing the intake screen in a bucket as shown in figure 9-7.

The level of the water in small streams can be raised to cover the intake strainer by building a dam.

In swiftly flowing streams, a wing or baffle dam can be built to protect the intake screen without impounding the water.

Floats made of logs, lumber, sealed cans, or empty fuel drums can be used to support the intake strainer in deep water. Floats are especially useful in large streams where the quality of the water varies across its width or where the water is not deep enough near the banks to cover the intake strainer. The intake point can be covered by an adequate depth of water by anchoring or stationing the float at the deep part of the stream. The intake hose should be secured to the top of the float, allowing enough slack for movement



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Figure 9-6.—Surface intake with hose buried in gravel-filled pit.

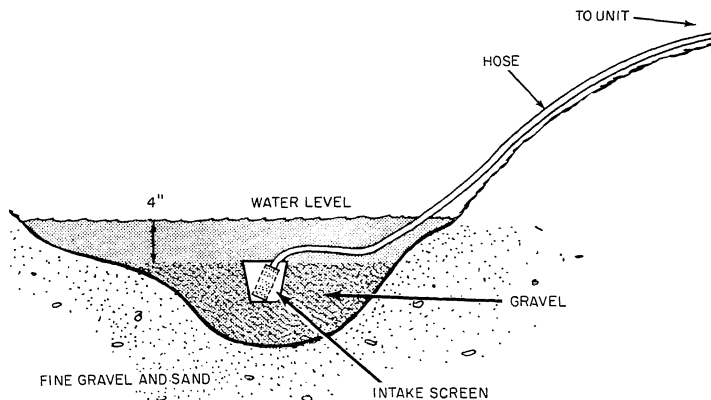


Figure 9-7.—Use of bucket on end of surface intake.

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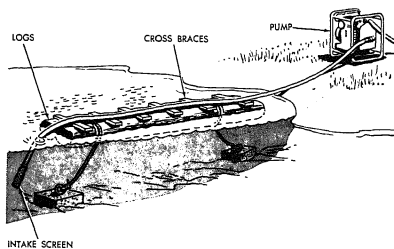


Figure 9-8.—Float-type surface intake.

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of the float. If support lines are used to secure the float to the banks, the position of the float can be altered to correspond to changes in depth by manipulation of the lines. The chief advantage of a float intake is the ease with which the screen can be adjusted vertically (fig. 9-8).

Water from muddy streams can be improved in quality by digging intake galleries along the bank. A trench is dug along the bank deep enough so that water from the stream percolates into it so it intercepts ground water flowing toward the stream. The trench is filled with gravel to prevent the sides from collapsing. The intake strainer is placed in the gravel below the water table (fig. 9-9). The amount of work required to produce

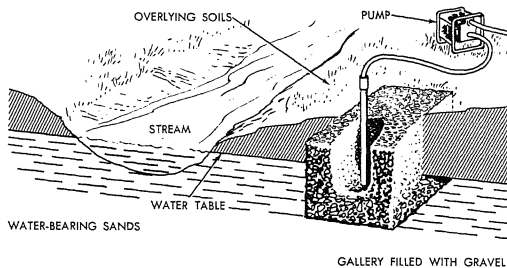


Figure 9-9.—Gravel-filled gallery intake.

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the gallery is justified by a reduction in the amount of chemicals needed to coagulate the water, the elimination of the necessity of frequently backwashing the filter, and the higher quality of water obtained.

GROUND WATER DEVELOPMENT

Moisture is held beneath the surface of the earth in three zones: (1) the zone of soil moisture, where water is temporarily held in pore spaces by capillary action or other soil conditions; (2) the zone of aeration or zone of percolation beneath the soil layer, where both water and air are present in the pore spaces; and (3) the zone of saturation, where all spaces are filled with water. *Ground water* is the term customarily used for the underground water in the saturated zone.

One possible objection to an underground water supply is that the water may be excessively hard. This condition may occur because of the percolation of the water through mineral deposits from which water-hardening constituents are leached or extracted. On the other hand, an underground supply generally has the advantage of requiring less treatment because of the natural removal of impurities as the water passes through various underground soil formations. However, these conditions are general; some mineral deposits do not contribute to hardness, and some underground formations may not be of the type that effectively removes objectionable material.

Many times it is advantageous to use shallow ground water sources or percolated waters adjacent to a turbid surface water. Well points are issued in 2-inch diameters and 54-inch lengths. A drive cap is placed over the thread and the well point is driven into the ground with a sledge. Successive sections of pipe, each 5 feet long, are added and driven until the screen is well within the water-bearing media. Several well points may be connected in parallel to supply sufficient water to the raw water pump. In developing drive point sources, it must be remembered that the practical limit of suction lift of the pumps issued with field equipment is 22 to 25 feet at sea level. Suction-lift pumps can be used, therefore, only where the pumping level in the well will be within the limit of suction lift, or 22 to 25 feet below the position of the pump. At 5,000 feet above sea level, the practical limit of suction lift is only 20 feet. It should be noted that since a suction-lift pump must create a partial vacuum in the suction line, it is necessary that the line be absolutely airtight if the pump is to function properly.

Springs yielding 20 gallons per minute or more of water can be used as a source of field water supply if properly developed. Springs may be developed by enlarging the outlet of the spring and by damming and conducting water to storage. To reduce possible pollution, springs should be cleared of all debris, undergrowth, top soil, loose rocks, and sand.

Water that flows from rocks under the force of gravity and collects in depressions can be collected in boxes or basins of wood, tile, or concrete. The collecting box should be large enough to impound most of the flow. It should be placed below the ground level so only the top is slightly above the surface. The box should be covered tightly to prevent contamination and lessen evaporation. The inlet should be designed to exclude surface drainage and prevent pollution. This requires fencing off the area and providing proper drainage. Figure 9-10 shows a spring inlet protected in this manner. The screen on the overflow pipe prevents the entrance of insects and small animals. Another screen on the intake pipe prevents large suspended particles being ingested by the pump used to distribute the springwater. This prevents mechanical failure or reduces it to a minimum.

The flow of water from a spring located on a steep slope of loose earth can be obtained by the following two methods.

- Constructing deep, narrow ditches leading from the spring to the point of collection.
- Constructing pipeline tunnels from the spring to the collecting points. Pipe of large diameter is more suitable for this purpose. The water from the tunnels can be trapped by constructing a dam at the point of collection.

Digging is a more positive and more economical method of developing a spring than blasting. You must proceed with great caution if you use explosives to develop the yield from springs. Blasting in unconsolidated rocks may shift the sand or gravel in such a way as to divert the spring to a different point.

The method used for the development of springs as a water source will depend upon the extent and characteristics of the flow. Thermal (hot) springs should not be developed since their waters are likely to be highly mineralized.

Regardless of the type of construction, all springs must be covered. Surplus water should be piped from the structure so surface water cannot

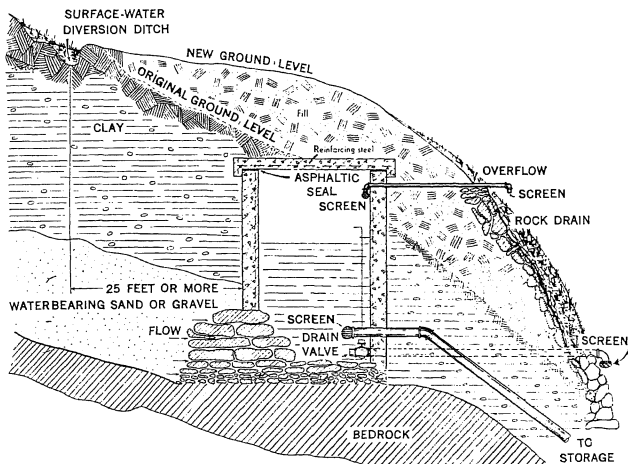


Figure 9-10.—Protection of spring from surface contamination.

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enter the spring during periods of flood. It is not necessary to ventilate spring structures; therefore, all openings should be avoided, except for an inspection manhole fitted with a tight, locked cover.

When ground and surface water supplies are inadequate or cannot be used, ground water supplies are developed by constructing wells. Wells are classified into five types, according to their method of construction. These are dug, bored, driven, jetted, and drilled wells. Each type of well has its particular advantages, which may be ease of construction, type of equipment required, storage capacity, ease of penetration into certain types of formations, or ease of safeguarding against pollution.

In the event of chemical, biological, and radiological operations, it is important to note that ground water would probably remain essentially uncontaminated by airborne or surface dissemination, in contrast to surface water, which could become severely contaminated. This does not mean that ground water is always pure and safe to drink. It can be naturally contaminated or could, in some cases, become contaminated with CBR agents. Well water should be thoroughly tested before use.

The production of ground water involves the method of recovery of water stored in the zone of saturation below the waterline or water table. The ground water table does not always remain at the same elevation, as it is controlled by rainfall, tides, the pumping rate from wells, and so forth.

A *dug well* is a large diameter well, seldom less than 3 feet in diameter, excavated with hand tools, and lined with brick, stone, steel, wood cribbing, or tile. That portion of the lining through the water-bearing formation is porous. This shallow type of well is usually dug from 20 to 40 feet deep, depending upon favorable location for water. Because of the large opening and perimeter to be protected against the incursion of surface drainage, dug wells are easily polluted by surface wash.

Bored wells are constructed in soft water-bearing formations that will not cave in while the hole is being bored. They are usually bored with hand or powered earth augers to a depth ranging from 25 to 60 feet without caving in.

Jetted wells are suitable in soft, unconsolidated, alluvial deposits. The well consists of an inner tube which is a drilling or jetting tube and an outer tube which is the well-casing. A

power-driven pump with suitable hose attachments supplies continuous water pressure during drilling. One type of rig uses a block and tackle or a tripod for controlling the tools and casing. Larger rigs have a mast and hoisting block and use engine power for handling casing, drive weight, and pump. Water is led into the well through a small diameter pipe and forced downward through the drill bit against the bottom of the hole. The stream loosens the material, the finer portion of which is carried upward and out of the hole by the ascending water. During the drilling, the jet or drill is turned slowly to ensure a straight hole. Casing is sunk as fast as drilling proceeds. In softer materials, by using a paddy or expansion drill, a hole may be made somewhat larger than the casing. The casing then may be lowered a considerable distance by its own weight. Ordinarily a drive weight is needed to force it down. As a rule, one size of casing is used for the entire depth of the well. It is difficult to drive a single string of casing beyond 500 to 600 feet by this method. If a well is sunk much deeper, an additional string of smaller size must be used. In fine-textured material the hole often may be jetted to the full depth and the casing inserted afterward. The wall of the hole becomes puddled by the muddy water so it will stand alone.

A *driven well* is constructed by driving a pointed screen, or drive point, and attached pipe directly into a water-bearing formation. The finished well consists of a series of lengths of pipe fitted at the upper end with a pump and the lower end with a sand screen through which the water is admitted. The drive point consists of a perforated pipe with a mild steel point at its lower end to break through pebbles or thin layers of hard material. As the drive point is driven down, succeeding sections are screwed into place. These sections continue until the water-bearing formation is reached. The pump then is attached, and after the well has been developed, it is ready for use. Drive point wells usually range in diameter from 1 1/4 to 2 inches, but larger sizes up to 4 inches also are made. The larger sizes, although of greater weight and more difficult to drive, have the advantage that deep-well pumps can be used when necessary. The smaller sizes, because of their lesser weight and greater portability, are valuable for determining the depth of water-bearing formations and for test yields at shallow depths. The depth of the well is limited by the formations encountered and by the type of pump available. For small wells, the ground water level must be

within 25 feet of the surface because suction pumps generally are used. If small self-priming centrifugal pumps are used, the lift must be less than 25 feet. If 2-inch or larger pipes are used, it is possible to lift water from a greater depth by installing a cylinder-type pump near the water level.

The following conditions are necessary for successful driven wells. The formation into which the point is being driven must not be too hard and compact. The distance to ground water must not exceed the lift of the pumps available. The water-bearing formations must have moderately high permeability to provide adequate yields in small-diameter wells. The wells must be developed properly to obtain sufficient water.

Chief disadvantages against general use of driven wells are as follows. Construction is laborious and slow when tightly compacted soils are encountered. Driving is destructive to well equipment; points frequently are stripped of mesh; pipe is bent and broken. Couplings frequently are belled by the force of the hammer blows. Belled joints always leak air and either render the well useless or seriously impair the yield of water. Yields are small from any one well point. As many as five points connected in series may be required to operate a power pump to capacity.

Successful construction of driven wells depends upon close observation and correct interpretation of events (occurring while driving) by the well driver. Accurate interpretation of such details as the penetration made with each blow, the drop and rebound of the monkey, the sound of the blow, and the resistance of the pipe to rotation enables the experienced well driver to determine the character of the materials being penetrated. An approximation of the geological section of the well can be obtained by recording these observations. Study of the logs for successive wells, coupled with a study of the results obtained from each well, assists in developing trained well drivers with each successive well.

Although a well site may have been properly selected, the strata correctly interpreted, and the presence of water accurately judged, wells may fail to yield water merely because they have not been pumped to clear the fine sediment from around the screen. When the presence of water is suspected, a simple test is to pour water into the well. If the screen is in dry sand, the water sinks downward and seeps into the formation, but if the screen is in saturated sand, the level of the added water remains nearly stationary or quickly sinks to a static level. Also the quantity

of water that can be poured into the well is an index of the well capacity when pumping; when saturated, the sand yields its contents as freely as it absorbs water. Often the raising or lowering of the pipe a foot or more brings a greater length of the screen into contact with the water-bearing stratum and results in a great increase in yield.

There are two methods of drilling wells, one is the hydraulic rotary and the other is the cable-tool percussion. Drilled wells tend to be the most complicated and require a lot of equipment. In most cases Equipment Operators will be called upon to place drilled wells. The Utilitiesman may be called upon to install pumps and plumbing when the drilling is complete. Development of this type of well will then proceed in a similar manner as any other type of well.

ALTERNATIVE WATER SOURCES

In some regions of the world there is not enough surface or ground water available to support the demands for domestic and fire protection water needs. In these areas it may be necessary to develop alternate sources of water. Rainwater, snow, seawater, water barges, and mobile tanks are a few of the alternate water sources that may be considered.

In tropical regions there is an abundance of rainwater with a rapid rate of surface runoff. The construction of collection surfaces can be a solution to water needs.

For temporary or emergency water supplies, collecting surfaces may be constructed by the use of tarps, wooden platforms, metal surfaces, and so on. Usually, however, surfaces constructed for other purposes, such as building roofs, may be used.

More permanent rainwater catchment areas will be cleared, graded, and given an application of cement or other impervious mixture. The catchment area should be located at least 100 feet from any source of subsurface contamination (septic tanks, cesspools, and so on), and as far from other sources of pollution (dust, soot, and so on) as possible. The catchment area and impounding basin should be enclosed by a fence.

Collected waters should be carried by gravity or pumping to closed storage reservoirs. As rain falls toward the earth, it absorbs dust and such gases as carbon dioxide and oxygen, and, therefore, must be considered unsafe for consumption until treated. Filtration and disinfection are the minimum required treatment.

In some locations water may be so hard to obtain or polluted that it would not be economical to develop any source. In this case, water barges or mobile tanks may be used. Barges or mobile tanks can be filled from ships, tank trucks, or other well points located some distance away. It is important to note that all mobile containers are a temporary water source. Disinfection of their surfaces that will come in contact with potable water is required.

In northern arctic areas where deep wells cannot be sunk through the thick layers of permafrost, and the surface sources are frozen solid, water must be obtained by melting snow or ice. Ice is preferred to snow because it will yield more water for a given volume. Snow or ice may be contaminated. Therefore, all melt produced should be treated before drinking. Approximately 5 cubic feet of snow is required to yield 1 cubic foot of water. In emergencies, personnel can eat small quantities of snow. This snow should be placed in the mouth, rather than being sucked, to prevent chapped or cut lips. Only small quantities of snow should be consumed in this manner because consumption of large quantities will reduce the body temperature.

Seawater is vastly different in its characteristics (as well as in the methods of purification used) from other surface sources. The chemical characteristics of seawater are such that normal coagulation and filtration are ineffective as treatment processes.

In developing seawater sources, consideration must be given to such factors as surf action, saltwater corrosion, suspended sand and silt in the water, living organisms, surface oil along beaches, and the rise and fall of the water level with the tides. If the equipment is located on sheltered bays, harbors, lagoons, or estuaries, it can be supplied by intakes built in the same way as freshwater surface intakes. On small islands where there is insufficient surface and ground water, and on or near open beaches, intakes for equipment can be built as follows:

1. Saltwater wells. Beach wells should, if possible, be used in preference to offshore intakes. Wells can be dug to tap fresh or salty ground water. This eliminates the problems caused by tides, surf, and shallow water close to shore. Such wells have an added advantage in that they can be built back of the shoreline under natural overhead concealment. Driven and jetted wells may also be used effectively at beach locations.

2. Offshore intakes. Offshore intakes are sometimes required because of lack of time, personnel, or equipment or because of coral conditions that prohibit well construction. Intakes of either the rigid pipe or float type may be used but they should be located in deep water beyond the surf. They must be positioned vertically and be off the bottom but still beneath the water surface at low tide. In this way foreign materials in the water which might cause excessive wear on equipment will be largely excluded. The rigid pipe intake can be placed on timber supports and anchored securely in position by piling or riprap. Floats securely anchored can support the intake screen in much the same manner as in surface waters. A rubber suction hose can be used to connect the rigid pipe on the sea bottom to the pipe supported beneath the float.

WATER CONTAMINATION

Water takes on various characteristics and properties as it passes over and through the earth. These characteristics and properties vary and are dependent on the materials encountered. These materials may be natural or man-made and are classified according to their means of detection.

- Physical—detected by one or more of the human senses
- Chemical—detected by chemical analysis
- Biological—detected by testing for chloroform organisms
- Radiological—detected by radiac equipment and special laboratory field tests

PHYSICAL IMPURITIES

Physical impurities in water are either suspended or dissolved. The suspended impurities are usually more dangerous to health. They include mineral matter, disease organisms, silt, bacteria, and algae. They must be destroyed or removed from water that is to be consumed by humans.

The most important physical characteristics are turbidity, color, odor, taste, and temperature. Valuable information can be obtained by observing the water with any of the five human

senses and using commonsense judgment on the following characteristics:

- Color
- Turbidity
- Odor
- Taste (use with caution)
- Temperature
- Condition of vegetation around source (dead or mottled vegetation can indicate the presence of chemical agents)
- Presence of dead fish, frogs, and so forth

Before starting any treatment to remove color, turbidity, taste, or odor, you should take several preventive measures.

You must prevent the formation of algae in raw water supply points. Algae can be controlled with copper sulfate, chlorine, or activated carbon. Before deciding which method or combination of methods may be most effective, consider the following factors:

- Volume of water to be treated
- Time of year
- The effects of treatment on fish life
- Type of secondary water treatment in use
- Equipment available
- Cost of treatment

You must also prevent the raw water source from becoming polluted by drainage from industrial waste and surface drainage from farms, mines, and watersheds.

The above conditions usually cause water to take on color due to the presence of colored substances in solution, such as vegetable matter dissolved from roots and leaves. Dissolved humus, iron, and salts could also be included. True color is due to substances in true solution, apparent color includes true color and substances in suspension rather than dissolved. Color may also be caused by industrial wastes and turbidity. Color as such is harmless, but objectionable

because of its appearance and the taste and odors sometimes associated with it.

Turbidity is a muddy or unclear condition of water caused by particles of sand, clay, or organic matter being held in suspension. Clay and silt remain suspended in water for the longest period of time because of their particle size and specific gravities. The removal of turbidity is essential to the production of potable water. Removal reduces water contamination, extends the time between backwashing of filters, decreases chlorine demand, improves disinfection, and enhances the user acceptability of the finished water. Proper water treatment requires turbidity removal because suspended particles often contain organisms that may cause diseases.

Turbidity is removed by coagulation and sedimentation. Since the physical characteristics of raw water vary widely in different locations, dosages of coagulant chemicals must be determined at each water point to ensure maximum efficiency and minimum waste of chemicals. After coagulation and settling, the water should not have more than 20 percent of the original turbidity. Daily jar tests will help check the optimum chemical dosage required to meet this standard.

Taste and odors in water must be considered from the user's acceptability point of view. Tastes and odors found in water are most commonly caused by algae, decomposing organic matter, dissolved gases, or industrial wastes. Potability is not normally affected by the presence of odors and tastes. On the other hand palatability is frequently affected, particularly when a substance such as bone or fish oil is present. Tastes and odors that make water unpalatable must be removed. Use of free available chlorine, aeration, and activated carbon will do much to prevent or remove unacceptable tastes and odors from treated water.

The use of free available chlorine is advantageous because most odors and tastes are removed and rigorous disinfection is assured.

Activated carbon is the most widely used single process for taste and odor removal. Aeration and copper sulfate treatment are also used. All three methods are described below. The method used will depend upon the substance or substances to be removed and available equipment.

- **Activated carbon.** Activated carbon is an excellent absorbing agent to use in ridding water of unpleasant tastes and odors. It is also an effective agent for removal of organic color. It

is insoluble and tends to float unless all particles are thoroughly wetted by being made into a slurry before being added to the water. When continuous flow equipment is being used, the activated carbon is added to the limestone feeder and added to the water with the limestone slurry. When batch-type equipment is being used, the activated carbon may be added with the other chemicals in the coagulation tank. Being insoluble, activated carbon will not affect the pH value or chemical characteristics of water. One ounce of activated carbon per 1,000 gallons of water is usually adequate. However, dosages up to 1 pound per 1,000 gallons can be used, depending upon the kind and degree of impurities present. Use of activated carbon in much higher dosages for removal of chemical agents is discussed later in this chapter.

NOTE: Treatment with activated carbon should always be made ahead of, or part of, the coagulation process, so the activated carbon and the various impurities absorbed by it will be removed.

- **Aeration.** This treatment consists of adding oxygen by exposing the water to air. The process has a twofold action. Volatile taste- and odor-producing materials are released to the atmosphere and the action of the air upon readily oxidizable materials causes a precipitation of insoluble oxides and hydroxides. Removal of hydrogen sulfide is an example of the former action, while removal of iron is an example of the latter action. The aeration of water to rid it of the taste and odor of decomposing vegetable matter generally involves both actions.

- **Copper sulfate.** If tastes and odors are caused by small living organisms in the water source, they may be controlled or prevented with use of copper sulfate. This treatment is most frequently used in lakes and reservoirs. The copper sulfate is applied either by towing a porous sack containing copper sulfate crystals behind a boat, or by spraying a solution over the surface of the water. The amount of copper sulfate used depends on the type and concentration of organisms present. Dosages should be controlled because amounts greater than 2.0 parts per million (ppm) will generally kill all fish in the water. The amount necessary to remove microorganisms has no detrimental effect, however, on human beings. Copper

sulfate treatment is rarely used in field water supply for several reasons.

1. The advantage to be derived from treating an entire lake or reservoir frequently does not warrant the expense of the treatment, when the length of time the water source is to be used is taken into consideration.

2. The amount of copper sulfate used entails considerations of wildlife, medical effects, and total water chemistry which are beyond the water supply technicians' area of operation.

3. Superchlorination and dechlorination with activated carbon are effective for short periods although they are expensive for extended operations.

Temperature is also a physical characteristic that must be considered in the treatment of water. Warm water tastes flat. Lowering the temperature of water suppresses odors and tastes and, therefore, increases its palatability. In the summer the temperature of deep lakes and reservoirs decreases sharply from top to bottom. By shifting the depth of intake, it may be possible to draw relatively cool water even during hot weather. Water should be drawn from the lower depths when possible. Cool water is more viscous than warm water and thus is more difficult to filter. Cool water is more difficult to coagulate and effectively chlorinate than warm water because of slower reactions. Water treatment rates should be reduced when water temperatures are less than 45 °F.

CHEMICAL CHARACTERISTICS OF WATER

The most important chemical characteristics of water are its acidity, alkalinity, hardness, and corrosiveness. A water treatment supervisor must be aware of these characteristics and the procedures for analyzing and treating the various chemical impurities that may be found in raw water. Chemical impurities can be either natural, man-made (industrial), or be deployed in raw water sources by enemy forces.

Some chemical impurities will cause water to behave as either an acid or a base. Since either condition has an important bearing on the water treatment process, the pH value must be determined. Generally the pH influences the corrosiveness of the water, the amount of chemical dosages necessary for proper disinfection, and the ability of an analyst to detect contaminants.

Refer to *Utilitiesman 3 & 2*, volume I, chapter 10, for the procedures for testing the pH value of water.

Hardness

Hardness is caused by the soluble salts of calcium, magnesium, iron, manganese, sodium, sulfates, chlorides, and nitrates. The degree of hardness depends on the type and on the amount of impurities present in the water. Hardness also depends on the amount of carbon dioxide in solution. Carbon dioxide influences the solubility of the impurities that cause hardness.

The hardness caused by carbonates and bicarbonates is called *carbonate hardness*. The hardness caused by all others (chlorides, sulfates, nitrates) is called *noncarbonate hardness*.

Alkalinity is usually equivalent to the carbonate hardness. Sodium, however, also causes alkalinity. In natural waters, sodium is not normally present in appreciable amounts. Therefore, in natural waters, the alkalinity is equal to the carbonate hardness. After water has been softened, however, a large amount of sodium remains in the treated water. In softened water, the total alkalinity is the sum of the carbonate alkalinity plus the sodium alkalinity.

Hardness is undesirable in that it consumes soap, makes water less satisfactory for cooking, and produces scale in boilers and distillation units.

The following minerals cause hardness in ground and surface waters:

- Calcium carbonate. Alkaline and only slightly soluble; causes carbonate hardness and alkalinity in water.

- Calcium bicarbonate. Contributes to the alkalinity and carbonate hardness of water. Calcium bicarbonate when heated produces carbon dioxide and calcium carbonate. This calcium carbonate precipitates as scale in boilers and distillation units.

- Calcium sulfate or gypsum. Causes non-carbonate hardness in water. Being more soluble in cold water than in hot, it separates from the water in boilers and forms scale on the boiler tubes.

- Calcium chloride. Causes noncarbonate hardness in water. In steam boilers and distillation units, the presence of calcium chloride can cause chemical reactions that result in pitting of the boiler tubes.

● Magnesium carbonate (magnesite) and magnesium bicarbonate. Act the same in water as calcium carbonate and bicarbonate.

● Magnesium sulfate (epsom salts). Adds to the noncarbonate hardness of water and causes boiler scale. In amounts greater than 500 parts per million in drinking water, it acts as a laxative.

● Magnesium chloride. Has the same properties and effects as calcium chloride. However, the magnesium will contribute to the formation of magnesium hydroxide scale on boilers and evaporators.

● Iron. Iron is undesirable because it imparts a rusty color and objectionable taste to water. It also forms crusts in plumbing and piping. When iron is present in water, organisms whose life processes depend on iron compounds may also be present. These organisms may cause tastes and odors and create what is called *red water*.

● Manganese. While not encountered as often as iron, it is found in both surface and ground water. Its presence in water normally causes a grey or black color. The total concentrations of iron and manganese in potable water should not exceed 0.3 ppm.

Iron and manganese removal is not normally required in the production of field drinking water. Oxidation by aeration, followed by sedimentation and filtration, is the most common method of removing iron and manganese. They are oxidized to insoluble ferric oxide and manganese oxide by this process. The same methods may generally be used to remove both iron and manganese, although when they are present together in water, removal is more difficult. Combinations of iron and manganese with organic matter may require aeration in trickling beds containing coke, followed by sedimentation and filtration. In some cases superchlorination followed by sedimentation and filtration will in itself remove these two substances. The addition of lime, Ca(OH)_2 , followed by sedimentation and filtration, is another method for removal of these substances.

The concentration of chemical substances present in water for military water supply should not exceed the values shown below. If local conditions or short-term requirements make the use of water containing higher chemical concentrations

necessary, authorization must be obtained from the medical officer.

Chemical Substances	Maximum	Values
Copper	1.0	ppm
Iron	0.3	ppm
Manganese	0.05	ppm
Zinc	5.0	ppm
Magnesium	125.0	ppm
Chlorides	250.0	ppm
Sulfates	250.0	ppm
Phenolic compounds	0.001	ppm
Lead	0.05	ppm
Hexavalent Chromium	0.05	ppm
Fluoride	1.5	ppm
Turbidity (silica scale)	5.0	units
Color (platinum-cobalt scale)	15.0	units
Nitrate-Nitrogen	10.0	ppm
Total solids	500.0	ppm

Water softening is the term used to identify the process of treating water supply hardness. Water softening is most likely to be necessary when water is being supplied to laundries and heating units involving boilers and steam equipment.

● Lime-Soda Process. Lime-soda ash softening consists of the application of these materials to the raw water. Lime, Ca(OH)_2 , reacts with the soluble calcium and magnesium bicarbonates and forms insoluble calcium carbonate and magnesium hydroxide. Soda ash, Na_2CO_3 , reacts with the soluble noncarbonate compounds of calcium and magnesium to precipitate insoluble calcium and magnesium compounds but leaves sodium compounds in solution. The physical operation of adding lime-soda ash and removing the precipitates is similar to that in the conventional coagulation-filtration process for bacteria and turbidity removal.

● Zeolite Process. Zeolites used in water softening are complex compounds of sodium, aluminum, and silica which have the faculty of exchanging bases. They are often called *green sand* because of the color of natural zeolite. Synthetic zeolites are also available. When water

containing calcium and manganese compounds passes over the zeolite, the calcium and manganese are exchanged for the sodium in the zeolite. In this way the water is softened and its sodium content increased. When the sodium of the zeolite is exhausted, it is regenerated by applying a sodium chloride solution. Another exchange is made, and the resulting concentrated solution of calcium and magnesium chloride is discharged to waste. The operating rate varies directly with the thickness of the zeolite bed. The time between regenerations depends on the characteristics of the water and the total amount of water applied. The need for regeneration will be evident when hardness is no longer removed. The zeolite process can only be used on water that has been treated for removal of turbidity.

- **Ion Exchange.** The ion exchange unit, when run on the sodium cycle, will significantly soften water. The ion exchange unit will also remove such undesirable ions as those of manganese and lead.

Dissolved Gases

The concentration of a gas in water is directly proportional to the concentration, or partial pressure, of the gas in the atmosphere in contact with the water surface. In general, this involves the water temperature, its salinity, and the altitude. The gases of primary interest to water supply are as follows:

- **Oxygen.** Large amounts of dissolved oxygen are found in rainwater. The amounts in surface water vary greatly, depending on the amount and type of pollution, the degree of self-purification, the action of algae, and the temperature of the water. Polluted water will exhaust the oxygen supply, while clean water will contain much dissolved oxygen. Cold water contains larger amounts of dissolved oxygen than warm; as water temperature rises, the dissolved oxygen is released to the atmosphere. Decreased pressure on water has the same effect, releasing oxygen to the atmosphere. Dissolved oxygen causes the solution of metals and, especially in the presence of carbon dioxide, causes many metals to corrode.

- **Carbon Dioxide.** The presence of carbon dioxide in water contributes to the degree of

hardness and acidity of the water. Water acquires this gas in four ways: from the air by natural movements of water in contact with the air, such as currents and wave action; by contact with decomposing vegetation, which gives off carbon dioxide freely; by the reaction of ferric chloride and limestone in the coagulation process; and by contact with the gas in underground deposits. A high carbon dioxide content usually makes water more corrosive to metals.

- **Hydrogen Sulfide.** Hydrogen sulfide in solution lends a disagreeable taste and rotten-egg odor to water. Ground water absorbs sulfides by passing over sulfur-bearing rocks. Hydrogen sulfide is also responsible for the destruction of cement and concrete as well as the corrosion of metals. In small amounts, it is unpleasant but not dangerous. In large amounts it is harmful. Water that smells of hydrogen sulfide should be treated.

Dissolved gases are removed by means of aeration or the use of activated carbon. Aeration exposes as much water as possible to the air. This will release dissolved gases such as hydrogen sulfide and carbon dioxide to the atmosphere. Liberating the dissolved gas from the water by aeration permits the oxygen in the air to come in contact with the finely divided water particles, thereby increasing the dissolved oxygen content of the water. This increase of oxygen content removes the offensive taste and odor imparted by the dissolved gases. Aeration raises the pH by eliminating the carbon dioxide, but increases corrosiveness by increasing the amount of dissolved oxygen. One type of aerator consists of trays containing slats or coke over which the water is sprayed. Other methods of aeration include spraying water up over a shallow receiving basin and forcing air into a basin with diffusers or mechanical pump-type aerators similar to those used in sewage treatment. Operation of most aerators is practically automatic; operators' duties consist essentially of making sure pipes, slots, and surfaces are not clogged and that air has free access to the water. If the water is not to be filtered after aeration, aerators must be screened to keep out insects and other foreign matter.

Activated carbon is a specially treated granular powdered carbon. It absorbs or attracts large quantities of dissolved gases. It is extremely

effective in taste and odor control, provided the

1. type of activated carbon used meets minimum standards,
2. dosage is correct,
3. carbon is mixed intimately with the water, and
4. carbon is in contact with the water for an adequate period.

Acceptable commercial preparations of activated carbon should meet the following minimum specifications:

1. It does not contain any soluble mineral injurious to health.
2. Moisture content is not over 8.0 percent.
3. It is powdered form that wets down and goes into suspension readily, does not settle too rapidly, and does not float on the surface when applied.
4. At least 99 percent of the carbon in water suspension passes a 100-mesh sieve and 95 percent passes a 200-mesh sieve.
5. It has enough adsorption capacity to reduce a concentration of 0.1 milligrams per liter (mg/l) phenol in distilled water to 0.01 ppm.

Because of the wide range in waters, no general rule can be given for activated-carbon dosage. The dose required at each water plant must be determined by periodic laboratory tests. The test is made by preparing a number of samples of raw water, adding the standard amount of treating chemicals and varying amounts of carbon to each sample, allowing plant contact time, filtering, and making odor tests. Numerical comparison can be made with the threshold odor test. A carbon dose of 3 ppm removes most tastes and odors from water. However, dosages can vary from 3 to 15 ppm, depending upon the odor of the water. Laboratory tests will determine the dosage.

Activated carbon is fed into the water by dry feeders. It must be handled more carefully than coagulants because it is a fine powder; therefore, the feeder must be an approved type and designed to prevent the spreading of the carbon dust and causing fires. In addition, inhaling of the dust by

personnel, even in low concentration, can affect their lungs. The dry feeder room should have explosionproof electrical equipment. A spark or pilot flame can create an explosion. Dry carbon will float on the surface of the water for a long time. Therefore, it is important that the carbon be wetted thoroughly, mixed by agitation using a paddle wheel, swirling action, a spray, or so forth, in a small tank. Some dry feeders have a mixing chamber in which the carbon is wetted by the swirling action of the water.

Activated carbon may be applied to the water at one or several points, depending on the results desired. Carbon is added at one or more of the following points:

- In the raw water, as early as possible after it enters the plant. This point of application is not recommended for extremely turbid waters.
- In the mixing basin. When added before sedimentation, activated carbon not only removes foreign matter from the water, but the carbon that settles in the sedimentation basin continues to absorb products of sludge decomposition, thus preventing formation of secondary tastes and odors. Black alum is premixed activated carbon and coagulant that can be used in special situations both as a coagulant and for taste and odor control.

CHEMICAL, BIOLOGICAL, AND RADIOLOGICAL (CBR) CONTAMINATION

Should chemical or biological agents or nuclear weapons be employed during conflicts, the water supply of the area involved would, in all likelihood, become contaminated. A water source contaminated with a chemical, biological, or radiological agent can cause incapacitation or death to a consumer. Effective means for determining the presence of CBR agents, followed by proper decontamination procedures, can reduce or eliminate the hazards caused by these agents.

In the event that you are assigned to supervise or manage a field water supply point, you will be responsible for the detection and removal of CBR contaminants. The supervisor of a water point crew must be sure the crew is trained in the identification of CBR contamination by

recognizing the various indications of CBR contamination of their water point as follows:

- An unusual taste or odor
- Dead fish and animals in unusually large numbers
- A sudden drop in normal pH values or a pH value of less than 6.0
- High readings on radiac equipment
- Personnel developing fevers, diarrhea, cramps, vomiting, and so forth
- Burning sensation of skin, eyes, and nose
- Runny eyes, nose, and mouth

If CBR contamination of a water source is suspected, have your crew don appropriate protective clothing and equipment before they start tests for determining the type and extent of the problem. This will prevent them from becoming casualties. For example, water contaminated with a nerve agent should not be allowed to come in contact with the skin nor the vapors be inhaled. Therefore, wearing a protective mask and gloves would be necessary before checking for nerve agent contamination.

Chemical Contamination

Chemical agents include the nerve agents (G-series and V-series), blister agents, vomiting agents, blood agents, choking agents, tear agents, defoliants, herbicides, smoke, and incendiaries. The nerve agents, blister agents, and agents containing cyanide are most dangerous because they are highly poisonous. Some are soluble in water, and either are slow to decompose in solution or remain poisonous after decomposition. Table 9-4 contains guidance for decontamination of chemical agents. Water supplies are likely to become contaminated as an incidental result of widespread chemical attack, rather than as a result of direct attack on the water supply.

Biological Contamination

Water is a carrier of many organisms that cause intestinal disease. An epidemic of one

of these diseases among troops can be more devastating than enemy action and can cause great damage to morale as well as health. A heavy responsibility thus rests upon the Utilitiesman, and vigilance over water purification equipment and procedures should never be relaxed. It is emphasized that water treatment methods to be used when certain chlorine-resistant organisms are encountered should be prescribed by a representative of the medical officer. The representative will recognize or anticipate the presence of these organisms and recommend such additional chlorination or other treatment methods as may be necessary.

A waterborne disease rarely produces symptoms in its victim immediately after the victim has drunk the contaminated water. A period of time known as the incubation period must pass before the victim comes down with the disease. During this incubation period the disease organisms are growing and multiplying. Absence of symptoms for several days after untreated water has been drunk is, therefore, no guarantee that the water is safe. Also, absence of disease among the local inhabitants is no assurance of safety, because they may have developed immunity.

Types of waterborne diseases include typhoid fever, paratyphoid fever, cholera, bacillary dysentery, amebic dysentery, common diarrhea, infectious hepatitis, and schistosomiasis.

More recent times have seen accelerated research and development in biological agents and means of dissemination. Biological agents, if used today, can be of major significance, and field water sources would undoubtedly be contaminated. The agents that could be used include the spectrum of pathogenic (disease-causing) organisms. In many ways biological agents resemble natural biological contamination that is removed by the usual water treatment process. However, contamination from biological agents could result in the presence of unusual microorganisms not normally found in field water and they could be present in abnormally high numbers.

Radiological Contamination

Although nuclear weapons have been used in combat, there are no reliable data as to the effect of nuclear explosions on field water

Table 9-4.—Decontamination and Minimum Potability Standards of Significant Chemical Agents

Substance	Symbol	Type	Decontamination Method	Allowable Concentration (ppm)	
				Short term (less than 7 days)	Long term (more than 7 days)
Arsenic	As	Blister Agent	Activated Carbon, 600 ppm	2.0	0.2
Lewisite	L	Blister Agent	Activated Carbon, 600 ppm	2.0	0.2
Mustard	HD	Blister Agent	Activated Carbon, 600 ppm	2.0	2.0
Nitrogen Mustard	HN-1 HN-2 HN-3	Blister Agent	Activated Carbon, 600 ppm	2.0	2.0
Hydrogen Cyanide (incl Cyanogen Chloride)	AC	Blood Agent	Warm water—aeration Cold water—1. Superhypo- chlorination, 100 ppm. 2. Dechlorina- tion, 600 ppm car- bon.	20.0	2.0
Nerve Agent (G)	GA	Nerve Agent	1. Superhypo- chlorina- tion 100 ppm.	0.1	0.1
	GB	Nerve Agent		0.05	0.05
Nerve Agent (V)	VX	Nerve Agent	2. Dechlorina- tion, 600 ppm car- bon.	0.005	0.005

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supplies. However, available fallout data leave no doubt that contamination of water supplies by this means must be considered. Since radiation is not detectable by human senses, instruments and laboratory tests are necessary to determine its presence.

A nuclear attack over or near a source of water supply will probably cause its contamination with radioactive materials. A nuclear explosion could cause contamination by any of the following

(listed in the decreasing order of importance to the water point operator):

- Fallout of fission products
- Induced activity in the water and surrounding soil
- Blow-in or wash-in of radioactive dust
- Fallout of unfissioned uranium or plutonium

The magnitude of contamination is dependent upon the yield of the weapon, the location of the detonation with respect to the water source, and whether it is air, surface, or subsurface burst.

TREATMENT OF CBR CONTAMINATION

If chemical, biological, or radiological agents, or any combination of these, are used, the field water supply will inevitably be involved. It is impossible to foresee what type of agent will be used, but effective security measures can decrease and counteract the hazards of all three types of agents.

Effective security involves prompt and accurate detection. Contamination by chemical agents usually, although not always, leaves significant signs that should arouse immediate suspicion. These are drastic lowering of the pH value of the water, characteristic odors and tastes, and dead fish. If chemical contamination is suspected, tests should be made with the Chemical Agent Water Testing Kit M272. A complete technical and operational breakdown of this kit can be found in Army TM-3-6665-319-10.

Advice and guidance from the medical officer must be sought and followed carefully when water contaminated by CBR agents must be treated and used. The specialized training of personnel in the latest means of detection and treatment will aid water supply technicians in safeguarding the lives and health of personnel.

If contamination of any type, by CBR agents or poisonous industrial wastes, is detected, every effort must be made to find an uncontaminated water source before considering treating and using water known to be contaminated.

If an uncontaminated source of supply is not available for use, permission must be secured from proper medical authority to proceed with treatment of the contaminated water.

Water is considered **CONTAMINATED AND UNSAFE** for treating if one or more of the

following results are obtained from competent testing:

Arsenic test	positive
Mustard test	positive
pH test	pH below 6
Chlorine demand test	positive
Nerve agent test	positive
Taste and odor test	positive

Water is considered safe for treatment by the usual methods if the pH is above 6.0 and all other contamination tests are negative.

When contamination by chemical agents has been determined to be present in concentration beyond the tolerance shown in table 9-4, and the water must be treated and used, one of the four types of decontamination methods set forth in the table is used.

1. **Activated carbon.** This treatment is used when blister agents are present. Activated carbon is a relatively pure, finely powdered form of carbon which absorbs many substances readily. It is an excellent absorbing agent because the fineness and porosity of the carbon particles give it an enormous surface area. One cubic inch of activated carbon particles has an internal and external exposure area of about 20,000 square yards. The activated carbon is added to a pretreatment tank set up separately from the coagulator assembly. Raw water is pumped into this pretreatment tank from the source, and the activated carbon added; 600 ppm is generally sufficient. The water is allowed to remain in contact with the carbon for 30 minutes or longer, and is then pumped to the purification unit for the usual treatment.

2. **Aeration.** When hydrogen cyanide is the contaminant and the water is warm (70°F or above), the aeration treatment may be used. Water may be aerated by spraying it into the air, allowing it to flow over cascades, passing it through beds of coke, or passing air under pressure into water. The spray method can be effectively used with most purification equipment. Water can be recirculated through storage tanks or reservoirs by pumping the water out of the tank and spraying it back through an elevated strainer or nozzle attached to the discharge end of the hose.

3. **Superchlorination and dechlorination.** (See Caution below.) When hydrogen cyanide is the contaminant and the water is cold (70°F or below) or when one of the nerve agents is the

contaminant, two pretreatment tanks should be used. Raw water is pumped into both tanks and superchlorinated by the addition of 100 ppm available chlorine from high strength calcium hypochlorite. (The calcium hypochlorite is added to the tanks before starting to fill them with raw water.) The water is then dechlorinated by the active carbon treatment outlined above. By the use of two tanks, a continuous quantity of pretreated water can be made available to the coagulator in much the same manner as two or more floc tanks are used in the batch process of normal water treatment. It is important that the residue of activated carbon in the pretreatment tanks be kept in suspension. Pumps should be used for this purpose if necessary. The carbon is removed by coagulation and diatomite filtration. If the residual is inadequate, postchlorination is necessary.

CAUTION

CALCIUM HYPOCHLORITE, A POWERFUL OXIDIZER, AND ACTIVATED CARBON, A REDUCING AGENT, WILL REACT VIOLENTLY, POSSIBLY RESULTING IN FIRE OR EXPLOSION, IF MIXED WITH ONE ANOTHER IN SLURRY FORM. THE FOLLOWING SAFETY PRECAUTIONS SHOULD BE OBSERVED:

DO NOT STORE ACTIVATED CARBON AND CALCIUM HYPOCHLORITE NEAR ONE ANOTHER.

DO NOT USE THE SAME PAIL TO PREPARE SLURRIES OF THESE TWO SUBSTANCES.

KEEP BOTH CHEMICALS DRY UNTIL ACTUALLY READY FOR USE.

When biological contamination has been reported by detection teams and an alternate uncontaminated source is not available, the prescribed treatment is superchlorination and dechlorination as described above.

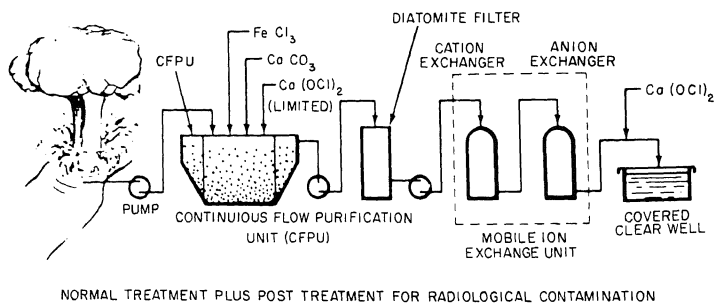
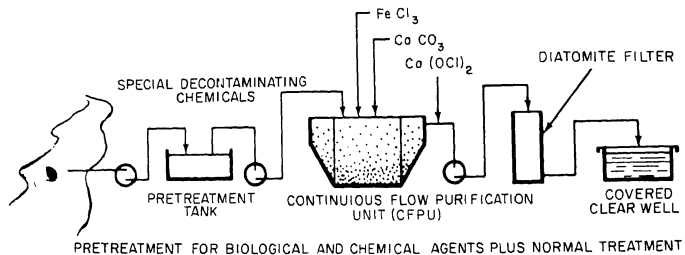
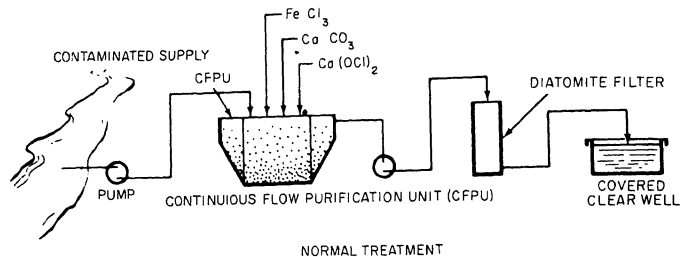
Radiological contamination may result from fallout of either fission products (radioactive isotopes) or unfissioned products (uranium or plutonium), as well as from blow-in or wash-in

of radioactive dust, and from induced activity in dissolved materials in water and surrounding soil. Continuous flow equipment, when operated according to standard procedure, is capable of removing a large amount of such contamination. However, sources containing radiological contamination should be avoided if at all possible.

The efficiency of a given process for removal of radioactive materials from water is dependent upon the quantity of the contaminant that is in suspension in the water and the quantity that is dissolved in true solution. Removal of material in suspension is relatively easy, since the purification procedure is designed to remove suspended matter and to clarify the water. Available information indicates that most of the radioactivity occurring in fallout and debris from the detonation of a nuclear weapon is insoluble in water. This fact tends to simplify the decontamination problem.

Continuous flow type of equipment, with auxiliary processing equipment when necessary, removes radioactive material from water by one or a combination of methods: pretreatment, coagulation, and filtration. Coagulation and filtration are normal treatment given to all raw surface waters in operation of field purification units. Removal of suspended radioactive materials by this method is very high. Removal of dissolved radioactivity depends primarily upon the nature of the radioisotopes in question. The removal is negligible for strontium 90, iodine 131, and cesium 137, the three most hazardous materials. For certain other radioisotopes, such as yttrium, ionic removals well over 90 percent may be realized.

Pretreatment is suggested when the degree of radiological contamination indicates a combination of treatment methods, or when the more effective ion exchange equipment is not available. Pretreatment consists of batch slurring the contaminated raw water with a selected material having adsorptive and ion exchange capacity. The material of choice is clay, preferably of the montmorillonite type, high in hydrous aluminum silicate content. Raw water is slurred with 1,000 ppm for 30 minutes and is then coagulated and filtered. This series of steps will remove most of the suspended radioactivity and an appreciable percentage of the dissolved radioactivity.



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Figure 9-11.—Comparison of standard treatment with process for treating water contaminated by CBR agents—continuous flow method.

Figure 9-11 shows a comparison of field water treatment equipment setups for normal, chemical/biological, and radiological contamination removal and treatment.

WATER TREATMENT EQUIPMENT

The senior Utilitiesman may be called upon to select and set up various types of field water treatment equipment. You must be familiar with the theory of operation, the capabilities, installation considerations, and maintenance requirements of this equipment. This section covers three types of water treatment equipment. They are distillation, filtration, and disinfection units.

DISTILLATION

In areas where a satisfactory freshwater source cannot be located, and existing water treatment facilities are not usable, the distillation process can be used to obtain fresh drinking water from brackish water, seawater, or water containing excessive amounts of dissolved solids. Distillation is effective for removing radioactive contaminants from water.

Since the output of distillation equipment is limited and the process is expensive, its use is restricted to situations in which no other process is adequate. Continuous flow or batch-type water purification equipment is used whenever possible.

Theory of Operation

Distillation consists of heating water to form steam, separating the steam from the remaining water, and then cooling the steam so that it becomes water again (fig. 9-12). As the water is heated to form steam or water vapor, and the vapor is separated and then cooled, solids dissolved in the water do not vaporize, but remain behind in the raw water. A large amount of heat that is not evidenced as a rise in temperature is required to change (vaporize) boiling water into steam.

The process whereby the latent heat is removed and the steam becomes water is called *condensation*. Heat flows through the bottom of the evaporator, enters the water, and changes the water to steam. The steam is condensed in the condenser, its latent heat of vaporization being transferred to the water surrounding the tubes. A portion of the cooling water that has picked up heat in passing through the condenser is generally used as feed water for the evaporator. All dissolved solids remain in the equipment and noncondensable gases are vented to the air so that the resulting distillate is almost pure. Thus the distillation process is useful in producing water of an extremely high purity and low in total solids. Despite this high degree of purity, all distilled water must be disinfected before being consumed because of the possibility of recontamination during handling.

In thermocompression distillation, the latent heat of vaporization of steam is again used to

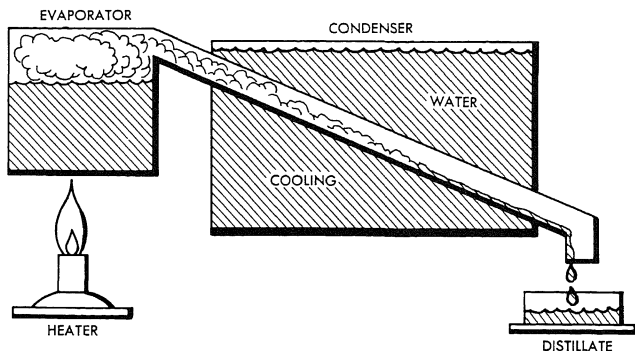


Figure 9-12.—Distillation in its simplest form.

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produce additional steam. The pressure and temperature of the steam generated in the evaporator are raised by compressing the steam. The compressed steam passes to the condenser section where it condenses, giving up its latent heat and causing more steam to form in the evaporator. This steam is then compressed and the cycle repeated. The use of a combination evaporator-condenser with a steam compressor creates a closed heat cycle, permitting the continued reuse of the latent heat of vaporization. The compressor is driven by a gasoline or diesel water-cooled engine.

Figure 9-13 shows the operation of a simple thermocompression distillation unit. Cold raw water flows through heat exchangers where it is heated almost to boiling by the outgoing streams

of distillate and brine, and by water from the engine that drives the compressor. The hot raw water flows into the evaporator-condenser and is changed to steam by the steam condensing in the tubes. This involves the transfer of latent heat. The steam in the evaporator is drawn into the compressor where it is compressed and its temperature raised (from 212°F to 222°F). The compressed steam flows back through the coils in the evaporator-condenser where it transfers its latent heat through the walls of the coil into the water in the evaporator section. This transfer of latent heat causes the steam to condense in the coils and changes the water in the evaporator into steam. This cycle will continue as long as the compressor runs. Presently the S200 SPD Vapor Compression Distillation Unit is found in the table of allowance. A complete description of the unit

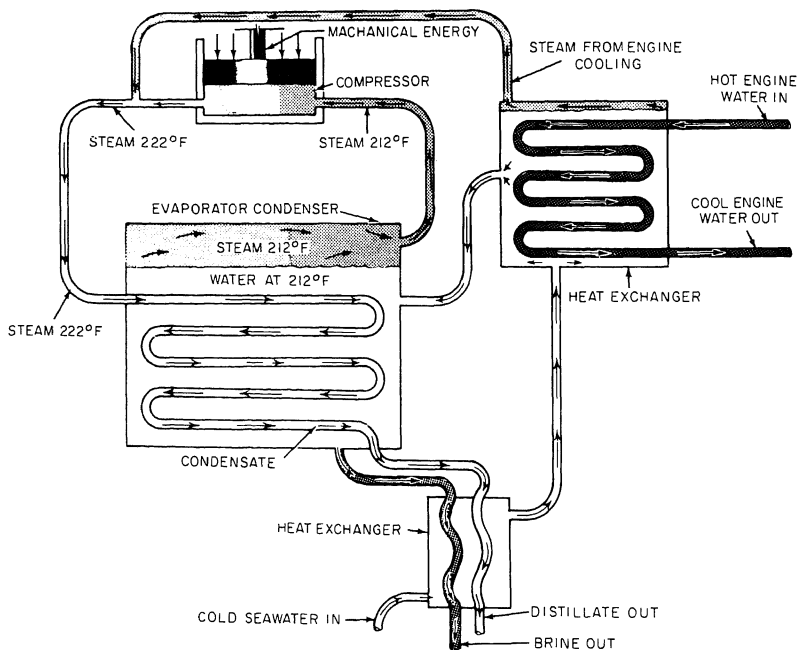


Figure 9-13.—Flow diagram—thermocompression distillation.

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and its operation may be found in *UT 3 & 2*, NAVEDTRA 10660, volume I, chapter 7.

Installation

At permanent naval activities, the installation of distillation equipment will be designed by engineers and improvements to the system can be made over a long period of time. In the tactical field environment, it will be the Utilitiesman supervisor who must consider various factors for the installation of distillation equipment. These are as follows:

- Potable water demand
- Site location
- Site drainage
- Security
- Fire protection

The demand for potable water will determine the number of distillation units, the need for storage facilities, operating hours, and so forth. You must determine the population you will be serving. Keep in mind that your water point may supply many units in an area, not just your organization.

The site location for distillation equipment must be upstream of any source of contamination. You must consider ocean currents that may change with wind direction, weather conditions, the season of the year, or tidal action. It is not efficient use of personnel or equipment if you have to relocate because the wind changed direction.

The site must also be relatively flat with a gradual slope toward the ocean. You also must allow for maximum tidal action. In many areas the tide may rise and fall several feet depending on the season of the year. Build low platforms to keep your equipment out of the sand and to allow air to circulate underneath tanks to prevent rot. These platforms will also prevent punctures of the storage tanks by sharp objects and provide a stable working area for operating personnel.

The importance of providing adequate drainage at any water point cannot be overemphasized. Waste water from filters, leakage from tanks, and spillage from distribution points can render a water point inoperable as well as creating an unsanitary condition.

Your water point may or may not be located in the vicinity of friendly forces. Denying the enemy information about your water point by using overhead concealment and camouflage may be necessary as well as guarding against ground attacks and sabotage with a defensive plan. Any adverse effect, from thirst to disease, the enemy can have on a water point will affect the well-being of the force using it. It will be considered in the enemy's plans.

Distillation equipment cannot produce water quickly enough to be used for fire protection. Do not permit your treated water to be used for this purpose except in extreme emergencies. Raw water should be used whenever possible.

FILTRATION

Filtration consists of passing the water through some porous material to remove the suspended impurities. Filtration is one of the oldest and simplest procedures known to man for removing suspended matter from water and other fluids.

The simplest form of water filter is the sand filter. This filter resembles a small reservoir, whose bottom is a bed of filter sand that rests on a bed of well-graded aggregate with the largest size aggregate being at the bottom. An underdrain system of tile or brick is provided under the gravel to collect the water from the filter area. The underdrain system consists of a header or main conduit extending across the filter bed. Means are provided for regulating the flow of water out of the filter through this header and also for controlling the rate of flow onto the filter. This allows the filter to be operated at controlled rates that should not exceed 3.0 gpm per square foot of filter area. An average filter bed consists of about 12 to 20 inches of gravel and 20 to 40 inches of sand. The depth of water over the sand bed varies from 3 to 5 feet.

The most effective filtration system ever devised and one of the most effective portable systems in existence is the diatomite filter unit

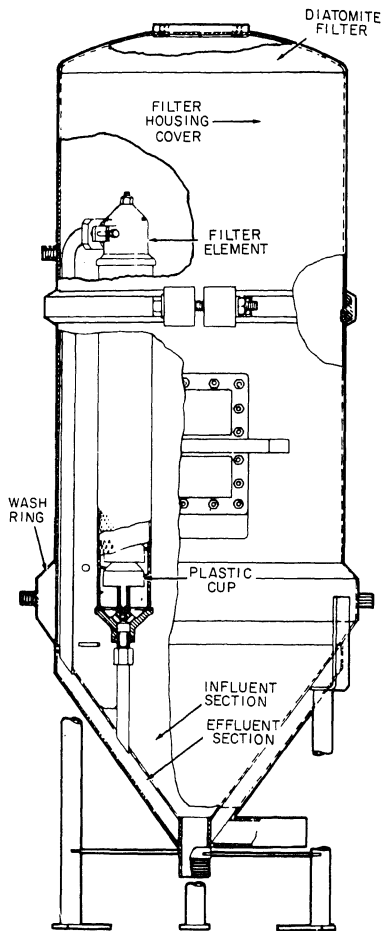
(fig. 9-14). In the diatomite filter, water is passed through a layer of diatomaceous silica (also called diatomaceous earth). It consists of skeletal remains of minute algae (diatoms) found in marine deposits that have lifted above sea level.

The diatomite filter accomplishes highly efficient filtration. Properly operated diatomite filters are capable of removing from coagulated and settled water, amoebic cysts, the cercariae of schistosomes, and approximately 90 percent of the bacteria. They also produce water with less than one unit of turbidity.

Before filtering, water is normally pretreated by passing it through sedimentation basins or holding tanks. This process removes heavier suspended solids that may cause rapid clogging of the filter. This water is brought onto the filters as the next step in the purification process. This water contains very finely divided suspended matter such as minute particles of floc, clay, and mud that have not settled, and bacteria and microscopic organisms that have not been removed by sedimentation. The purpose of the filter is to remove this suspended matter and give the water a clear, sparkling, and attractive appearance.

There are basically three types of filters. These are slow sand filters, rapid sand filters, and pressure filters.

Slow sand filters contain fine-grain sand and have low filtration rates. They are usually used when coagulation is not included in the treatment process. Their capacity is about 2 to 10 million gallons per day (mgd) per acre of filter surface. Use of slow sand filters has been practically discontinued because of their high cost per unit of capacity and the labor required to clean them. Rapid sand filters are now universally used in modern water treatment plants. There are two types, gravity and pressure. Gravity filters (fig. 9-15) are essentially open-top rectangular concrete boxes about 10 feet deep. An underdrain system at the bottom is covered by gravel, which, in turn, supports a 24- to 30-inch layer of fine filter sand (fig. 9-16). Gravity filters are usually designed to filter about 2 gpm per square foot of filter-bed area. However, in an emergency, up to 4 gpm per square foot can be obtained if prior treatment by flocculation and sedimentation produces very low turbidity and prechlorination and postchlorination or both are effectively disinfecting the water. Approval must be obtained from the major command to operate filters at rates in excess of 2 gpm



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Figure 9-14.—Diatomite filter, showing one filter element.

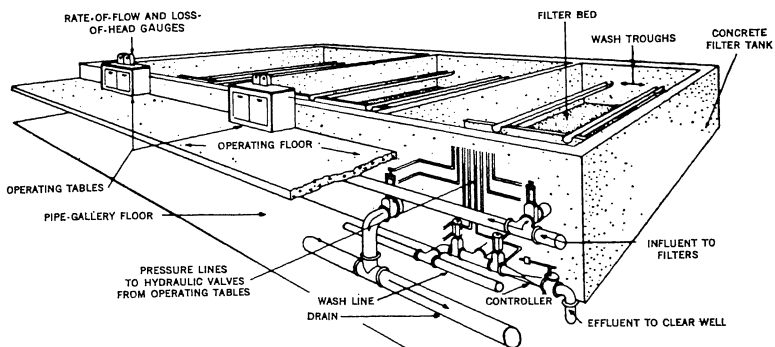


Figure 9-15.—Battery of three gravity-type rapid sand filters.

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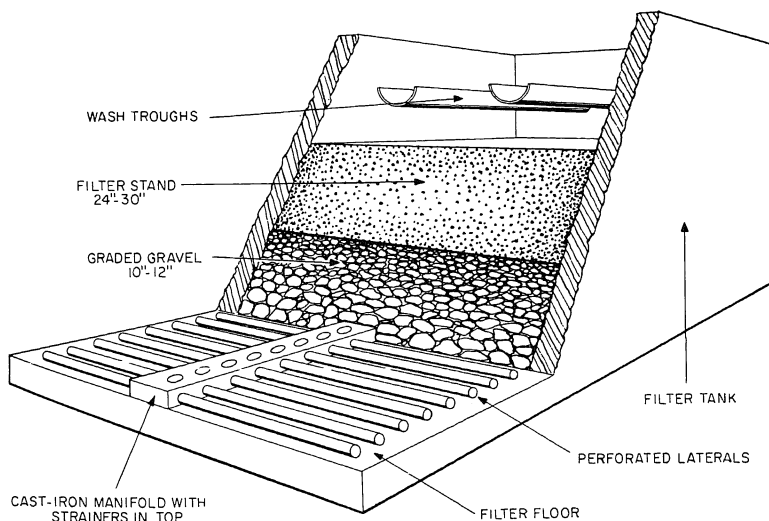


Figure 9-16.—Typical sand filter showing relationship of filter media.

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per square foot. Pressure filters (fig. 9-17) have the filter bed enclosed in a pressure vessel. Water is either pumped into the vessel and forced through the filter or is drawn into the vessel and through the filter by a pump. The diatomite filter is classified as a pressure filter.

DISINFECTION

Besides coagulation, sedimentation, and filtration, water must undergo an additional treatment step; disinfection. This is necessary because no combination of the other three steps can be relied upon to remove all disease-producing organisms from water; also because there is danger of recontamination during handling before consumption. Residual disinfection using chlorination is the final step in all water treatment processes (including distillation). Under emergency or field conditions, water may be disinfected with iodine or by boiling.

The most satisfactory means of water disinfection and provision of a residual is by means of a chemical disinfectant. The efficiency of the disinfection process is dependent upon numerous

factors. These include the chemical used, the contact time, the type and concentration of microorganisms, the pH and temperature of the water, the presence of interfering substances, and the degree of protection afforded organisms from the disinfecting solution by materials in which they are imbedded. Therefore, various concentrations of disinfectant are required depending upon the local environmental conditions and the amount of particle removal effected.

Chlorine is the most commonly used chemical for disinfection of water. It is used in field water supply in the form of calcium hypochlorite, a standard item in the supply system (commercially known as HTH powder). When the calcium hypochlorite is dissolved, the chlorine goes into solution and a calcium carbonate sludge settles out. The chlorine is present in the solution as hypochlorous acid or hypochlorite ion (depending on the pH). Both forms are powerful oxidizing substances. The chlorine available in either form rapidly oxidizes the organic and inorganic matter, including the bacteria in the water. In this reaction the chlorine is converted to chloride and is no longer available as a disinfectant. The organic matter as well as such material as iron and manganese consumes the chlorine. The use of chlorine makes it possible to introduce an accurately measured dosage to ensure the destruction of disease-producing organisms and provide a readily measured residual to safeguard against recontamination during further handling.

Chlorine dosage is the amount of chlorine added to water to satisfy the chlorine demand as well as to provide a residual after a specified time. The amount required to disinfect water varies with the organic content and pH value of the water, the temperature, the time of contact, and the chlorine residual required. The dosage is usually stated in terms of parts per million (ppm) or milligrams per liter (mg/l).

The chlorine demand of water is the difference between the quantity of chlorine applied in water treatment and the total available residual chlorine present at the end of a specified contact period. The chlorine demand is dependent upon the nature and the quantity of chlorine-consuming agents present and the pH value and temperature of the water. (High pH and low temperatures retard disinfection by chlorination.) For comparative purposes, it is imperative that all test conditions be stated. The smallest amount of residual chlorine considered to be significant is 0.1 ppm. The relationship of the demand to the length of the contact period is discussed below.

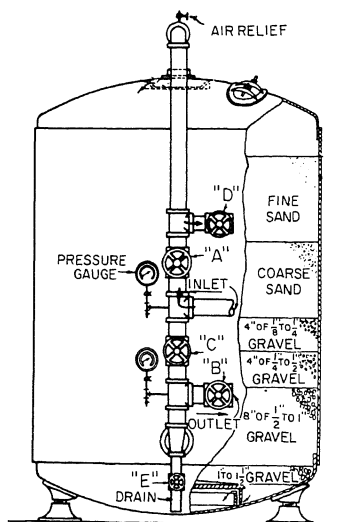


Figure 9-17.—Pressure filter.

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Some of the chlorine-consuming agents in the water are nonpathogenic (nondisease-causing organisms), but this bears no relationship to the fact that they contribute to the total chlorine demand of the water. Navy policy requires that for field water supplies, the chlorine demand must be satisfied and chlorine residual must be present.

Residual chlorine is the amount of unreacted chlorine remaining at a specified time after the chlorine compound is added. Chlorine in aqueous solution is highly unstable. It may change quantitatively and qualitatively under numerous conditions, including the presence of other elements or compounds. The total residual chlorine in the water can be chemically divided into several types.

- **Total available residual chlorine.** This is the sum of the free available chlorine and the combined available chlorine.

- **Free available chlorine.** This refers to hypochlorous acid and hypochlorite ion present in water. These are the most effective disinfection forms of chlorine. The free available chlorine is a rapid-acting type, important because it can be relied upon to destroy bacteria relatively quickly, and thus is active during the period immediately following chlorination. The relative amount of each present in the water is dependent upon the pH value of the water. It is important to remember that when the pH is raised, the quantity of free available chlorine required to kill the same number of microorganisms increases. With decreasing temperature, the same situation of increasing dosage to maintain the same kill is encountered. If the contact time is varied, then the dosage applied must also be changed. For example, to shorten the contact time the dosage would have to be increased.

- **Combined available chlorine.** This results from the presence of ammonia or organic nitrogen that will react to form simple chloramines. Thus the term *combined available chlorine* arises from the fact that the chlorine has combined with another substance. Chloramines are a slower acting and less active form of disinfectant. Therefore, a much higher concentration than that of free available chlorine is needed to produce the same germ-destroying effect. The specific chloramines present are also a function of pH.

Chlorine demand in most water is likely to be largely satisfied 10 minutes after chlorine is

added. After the first 10 minutes of chlorination, disinfection continues but at a diminishing rate. A standard period of 30 minutes' contact time is used to assure that highly resistant or high disease-producing organisms have been destroyed, providing a high enough dosage has been applied. Given a sufficiently large chlorine content, and if certain other conditions are met, even such special water purification problems as the presence of amoebic cysts or schistosomes will be solved with the 30-minute contact period.

The efficiency of the chemical disinfection process is dependent upon numerous factors. They include the type and concentration of microorganisms, the pH and temperature of the water, the presence of interfering substances, and whether or not the organisms are protected from the disinfection solution by being embedded in tissue cells, or clumps of tissue cells, or other material. Therefore, various concentrations of disinfectants are required. Minimum concentrations of disinfectants are prescribed below. Higher concentrations may frequently be prescribed by the medical officer on the basis of his knowledge of endemic disease or local environmental conditions.

SEABEE-operated mobile and portable water treatment units use coagulation and filtration as a part of the treatment process. They are capable of a high degree of removal of particulate material. When those units are used, sufficient chlorine will be added to the water, preferably before coagulation, so the residual in the finished water after 30 minutes of contact will be at least as much as that indicated by the following table.

pH	30-Minute Free Chlorine
	Residuals in mg/l
5	0.75
6	0.75
7	1.00
8	3.00
9	5.00
10	5.00

If adequate provisions are not made for accurate and frequent measurement of pH, 5.00 mg/l must be used. The following guidelines were used in developing the above table:

- The water to be treated would be natural surface or ground water of average composition and not grossly or deliberately contaminated.

- Water temperature would be above the freezing point.

- Treatment would consist of coagulation, sedimentation, and filtration through diatomaceous earth. Water plant operators would be well trained and dependable.

- The prescribed concentrations of free chlorine should provide a reasonable margin of safety for all bacteria and viruses pathogenic to man. Parasitic ova (eggs) would have been removed in the coagulation and filtration steps of the treatment process.

EMERGENCY TREATMENT METHODS

Emergency treatment methods using water sterilizing bags, canteens, and other water containers do not provide for removal of impurities by coagulation and filtration. The entire reliance for rendering the water safe for consumption is placed on the disinfection process. Sufficient chlorine is added to the water so the residual, after 30 minutes of contact, will be at least 5 ppm of total chlorine. Under certain conditions, such as the presence of highly resistant disease-producing microorganisms or adverse environmental conditions, the medical officer will designate such higher residuals as may be necessary.

Boiling is a quick means of disinfecting small quantities of water in the field by individual soldiers. It is likely that all bacteria that produce diseases in man are killed by pasteurization temperatures. But there are some resistant organisms, principally viruses (such as infectious hepatitis), for which water must be boiled to achieve inactivation. A practical minimum standard for altitudes from sea level to 25,000 feet is to bring the water to a rolling boil for 15 seconds. Longer boiling times may be prescribed by the medical officer on the basis of evidence that the minimum is not inactivating all pathogenic microorganisms. Upon cooling, the boiled water should be kept in a covered uncontaminated container. Boiling is obviously a difficult way to disinfect large quantities of water.

Breakpoint chlorination is the application of chlorine to produce a residual of free available chlorine with no combined chlorine present. As chlorine is added, the total residual increases gradually after the initial demand of the water has been satisfied. At some residual concentration, depending on the water treated, free available

chlorine reacts with the remaining oxidizable substances (including combined chlorine), and the residual drops sharply. When all combined chlorine has been oxidized by reaction with free available chlorine, the residual, now consisting only of free available chlorine, rises again and continues to increase in direct proportion to increased dosage. The point at which the residual again begins to increase is the breakpoint.

Figure 9-18 shows four typical breakpoint chlorination curves. Note that the curve rises at almost a 45-degree angle after the breakpoint is reached. Reactions are most rapid at pH from 6.5 to 8.5 and with increasing temperatures.

Curve 1 shows a typical breakpoint for water containing a considerable amount of ammonia. During the initial upward rise, chloramines are first formed. The curve rises until sufficient free available chlorine is developed to react with chloramine; then it falls until a point where all ammonia compounds have been oxidized.

With less organic matter in the water, as in curves 2 and 3, free available chlorine is formed sooner, destroying chloramines formed at the early stage. This results in lower combined chlorine residuals and flatter curves before breakpoint.

With practically no organic matter, curve 4 shows the chloramines are neutralized at an early stage by the upswing of the curve.

For some waters containing complex organic compounds, several intermediate breakpoints occur.

Advantages of breakpoint chlorination are high bactericidal efficiency, long-lasting residuals, and low odor and taste characteristics. It can be used only if detention periods are long enough to develop free available chlorine residual. This varies with the organic content of water. In some cases the treated water must be open to the air to permit escape of chloroorganic gases formed.

Tests for ammonia nitrogen will assist in determining the breakpoint. In practice, 10 to 25 times as much chlorine as ammonia nitrogen content may be needed to reach the breakpoint. Breakpoint chlorination, before instead of after filtration, has been found desirable. In surface water supplies with widely varying ammonia nitrogen content, the breakpoint chlorination should not be used unless trained assistance is available to make frequent tests for the breakpoint. With such water quality, the breakpoint curve can change radically in a short time.

Superchlorination is the application of more chlorine than needed for the chlorine residual

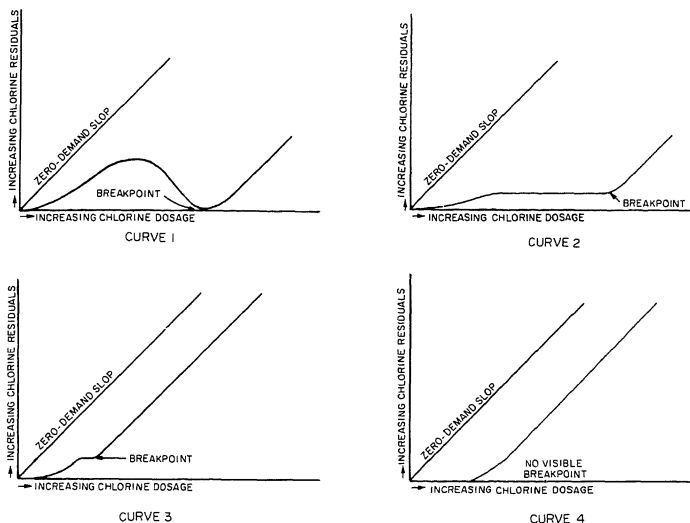


Figure 9-18.—Breakpoint chlorination curves.

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essential to marginal chlorination. The surplus, which is used to control odors and tastes, is later removed by dechlorination. This method is particularly valuable in surface waters with variable ammonia and organic content. Sulfur dioxide reacts with chlorine to form acids that are neutralized by the natural alkalinity of the water. Sulfur dioxide is fed by equipment similar to that used for chlorine feeding. Activated carbon absorbs the excess chlorine, while aeration removes it by dissipating it to the atmosphere.

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- Intermediate Water*, Naval Technical Training Center Course 215, Navy Public Works Center, Norfolk, Virginia 23511, May 1969.
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CHAPTER 10

SEWAGE TREATMENT AND DISPOSAL

Learning Objective: Identify the characteristics of sewage including the sampling and testing techniques used in identifying treatment and disposal requirements.

Sewage is the wastewater of community life. In composition it includes dissolved and suspended organic solids that are putrescible and, therefore, will decay. Sewage also contains countless numbers of living organisms—bacteria and other microorganisms whose life activities cause the process of decomposition. When decay proceeds under anaerobic conditions (in the absence of dissolved oxygen in the sewage), offensive conditions result and odors and unsightly appearances are produced. When decay proceeds under aerobic conditions (in the presence of dissolved oxygen), offensive conditions do not result and the process is greatly accelerated.

The promotion of cleanliness by the removal of filth and wastes to an area remote from the center of activity is important. It is only by such practices that the environment can be maintained in an acceptable and safe condition. Among the waste products of life are the disease-producing (pathogenic) bacteria and viruses that can be readily transferred by sewage from sick individuals to well ones. Properly regulated procedures for disposal of sewage are necessary to protect the health of the people and to maintain the cleanliness of the environment and the comfort of the inhabitants.

The degree of treatment used for sewage depends on two main considerations: (1) the protection of health of the command and community, and (2) the prevention of water pollution. The state or local authorities having statutory authority in pollution control usually have established standards of purity that are necessary to prevent pollution of natural waters. Accordingly, when a Navy installation discharges liquid waste into controlled waters, the standards set by state or local authority must be maintained.

The Utilitiesman may be involved in the installation, operation, and maintenance of the systems designed to meet the above requirements. This chapter will aid you in performing the varied duties and responsibilities of the first class and chief Utilitiesman involved in sewage treatment and disposal. A discussion of the sources, characteristics, sampling and testing procedures, and the monitoring of sewage disposal influents are given in this chapter. In addition to these subjects, septic tanks, cesspools, and leaching fields are also discussed.

SOURCES OF RAW SEWAGE

The major sources of raw sewage are domestic sewage, industrial sewage, and storm water.

DOMESTIC SEWAGE

Domestic sewage consists of wastes from toilets, lavatories, urinals, bathtubs, showers, home laundries, and kitchens. It also includes similar wastes from dispensaries and hospitals.

INDUSTRIAL SEWAGE

Industrial wastes, depending upon the source, usually have characteristics different from domestic flows. Some of these wastes can be dangerous to the plant operators as well as to the treatment plant and collection system. Industrial waste sources include, but are not limited to, laundry and dry-cleaning plants, metal-cleaning and plating processes, paint spray booths, aircraft and vehicle cleaning racks, boiler plants, photographic processing, and fire-fighting activities. Most industrial wastes require pretreatment before

being introduced into a collection system at their source.

Industrial wastes can also be very high or low in pH because of acids and/or bases used in their processes. You may expect intense colors in wastes from painting areas. Grit, salt, and dirt levels may be high from vehicle wash racks. Radioactive wastes must never be dumped into regular collection systems. They must be handled separately and, in most cases, very carefully. Explosive or flammable liquids can often enter the system from fuel storage areas. These liquids also create a dangerous fire hazard in a sewage treatment plant.

STORM WATER

Storm water should be excluded from the sewage collection system as much as possible. Heavy input of storm water can disturb the operation of a treatment plant by sending it too much water, a problem called *hydraulic overloading*.

This situation may force diverting or bypassing effluent from the treatment plant. Bypassing is normally a violation of National Pollutant Discharge Elimination System (NPDES) permits. These permits are controlled by the Environmental Protection Agency (EPA). Bypassing can result in releasing bacteria, heavy metals, and other dangerous contaminants into receiving waters. It is to be avoided whenever possible.

Very large paved or roofed areas should not be drained into the sanitary collection system. Maintenance personnel should prevent storm-water infiltration as much as possible by ensuring manholes are sealed, pipes are not cracked or broken, and all leaking joints are repaired.

SOURCE QUANTITY VARIABLES

Each military installation has different wastewater flows depending upon the types or

Table 10-1.—Characteristics of Typical Wastewater Generated at Military Facilities

Parameter	Weak	Medium	Strong
Total solids	330	700	1,200
Total volatile solids	240	420	810
Suspended solids	100	200	400
Total dissolved solids	230	500	800
Volatile suspended solids	70	130	220
Settleable solids*	2	4	6
Biochemical oxygen demand (5 day)	100	200	400
Total nitrogen as N	10	20	40
Ammonia nitrogen as N	4	10	20
Total phosphorus as P	6	10	20
Grease	50	100	150
Chemical oxygen demand	300	450	600
*All the above are measured in milligrams per liter (mg/l) except settleable solids, which are measured in milliliters per liter (ml/l).			

sizes of industrial activities. Normally, 80 to 120 gallons per day per permanent resident and 30 to 50 gallons per day per transient and community labor personnel can be used as a rough volume estimate for flow.

PATTERNS OF FLOW

The amount of wastewater a treatment plant receives fluctuates from hour to hour. Changing seasons also affect the pattern flow. Peak flow of domestic wastes normally reaches a plant just after breakfast and for several hours in the early evening. Industrial wastes may reach the plant during the industry's period of operation. If the industry has two or three shifts, flow will be more constant.

The size and topography of the area served by a treatment plant also affects the flow pattern. Small plants may have large differences between peak and low flow periods. Larger plants normally have more uniform rates of flow. The period of lowest flow is usually between 2400 and 0500 hours. Unusual flow patterns help operating personnel identify and correct abnormal surges in flow in the wastewater system.

CHARACTERISTICS OF SEWAGE

Sewage is composed of many materials that are broken down into three general areas. These areas are the physical, chemical, and biological characteristics of wastewater. This section will aid you in identifying these various characteristics.

WASTEWATER COMPOSITION

The concentrations of most materials in wastewater are expressed in milligrams per liter

(mg/l) and denote the strength of the wastewater. The higher the concentration, or mg/l, the higher the strength. Table 10-1 lists the most important materials that compose wastewater.

PHYSICAL CHARACTERISTICS

The physical characteristics of wastewater include those items that can be detected using the physical senses. They are temperature, color, odor, and solids.

Temperature

The temperature of wastewater varies greatly, depending upon the type of operations being conducted at your installation. Wide variation in the wastewater temperature indicates heated or cooled discharges, often of substantial volume. They have any one of a number of sources. For example, decreased temperatures after a snowmelt or rainfall may indicate serious infiltration. Changes in wastewater temperatures affect the settling rates, dissolved oxygen levels, and biological action. The temperature of wastewater becomes extremely important in certain wastewater unit operations such as sedimentation tanks and recirculating filters.

Color

The color of wastewater containing dissolved oxygen (DO) is normally gray. Black-colored wastewater usually accompanied by foul odors, containing little or no DO, is said to be *septic*. Table 10-2 provides wastewater color information.

Table 10-2.—Significance of Color in Wastewater

Unit Process	Color	Problem Indicated
Influent of plant	Gray	None
	Red	Blood or other industrial wastes or TNT complex
	Green, Yellow, Other	Industrial wastes not pretreated (paints, etc.)
	Red or other soil color	Surface runoff into influent, also industrial flows
	Black	Septic conditions or industrial flows

Odor

Domestic sewage should have a musty odor. Bubbling gas and/or foul odor may indicate industrial wastes, anaerobic (septic) conditions, and operational problems. Refer to table 10-3 for typical wastewater odors, possible problems, and solutions.

Solids

Wastewater is normally 99.9 percent water and 0.1 percent solids. If a wastewater sample is evaporated, the solids remaining are called *total solids*.

The amount of solids in the drinking water system has a significant effect on the total solids concentration in the raw sewage. Industrial and domestic discharges also add solids to the plant *influent*. There are many different ways to

classify solids. The most common types are dissolved, suspended, settleable, floatable, colloidal, organic, and inorganic solids.

Part of the total solids is dissolved in wastewater. Much like sugar dissolves in coffee, many solids dissolve in water. Dissolved solids pass through a fine mesh filter. Normal wastewater processes using settling or flotation are designed to remove solids but cannot remove dissolved solids. Biological treatment units such as trickling filters and activated sludge plants convert some of these dissolved solids into settleable solids that are then removed by sedimentation tanks.

Those solids that are not dissolved in wastewater are called *suspended solids*. When suspended solids float, they are called *floatable solids* or scum. Those suspended solids that settle are called settleable solids, grit, or *sludge*. Very small suspended solids that neither float nor

Table 10-3.—Odors in Wastewater Treatment Plant

Odor	Location	Problem	Possible Solutions
Earthy, Musty	Primary and Secondary Units	No problem (Normal)	None required
Hydrogen sulfide (H ₂ S), "Like rotten eggs"	Influent	Septic	Aerate, chlorinate, oxonizate
"	Primary Clarifier	Septic Sludge	Remove sludge
"	Activated Sludge Aeration Tanks Trickling Filters	Septic Conditions (Anaerobic)	More air or less BOD, recirculation rate, HTH, flood
"	Secondary Clarifier	"	Remove sludge and/or grease
"	Chlorine Contact Tank	"	Remove sludge
"	General Plant	"	Good housekeeping
Chlorinelike	Chlorine Contact Tank	Improper chlorine dosage	Adjust chlorine dosage controls
Industrial Odors	General Plant	Inadequate pretreatment	Enforce sewer use regulation

settle are called *colloidal particles*. Colloidal particles are often removed in the biological treatment units. They may also be removed by chemical treatment followed by sedimentation.

All the solids discussed above may be either organic or inorganic. *Organic solids* always contain carbon and hydrogen and when ignited to high temperatures (500°C to 600°C) burn to form carbon dioxide, water, and sometimes various other compounds. The burning or volatilization of organic solids has led to the term *volatile solids*. All solids that burn or evaporate at 500°C to 600°C are called volatile solids. These solids serve as a food source for bacteria and other living forms in a wastewater treatment plant. Most organic solids in municipal waste originate from living plants or animals.

Those solids that do not burn or evaporate at 500°C to 600°C, but remain as a residue, are called *fixed solids*. Fixed solids are usually inorganic in nature and may be composed of grit, clay, salts, and metals. Most inorganic solids are from nonliving sources. Table 10-4 summarizes the types and amounts of the solids discussed in the preceding paragraphs.

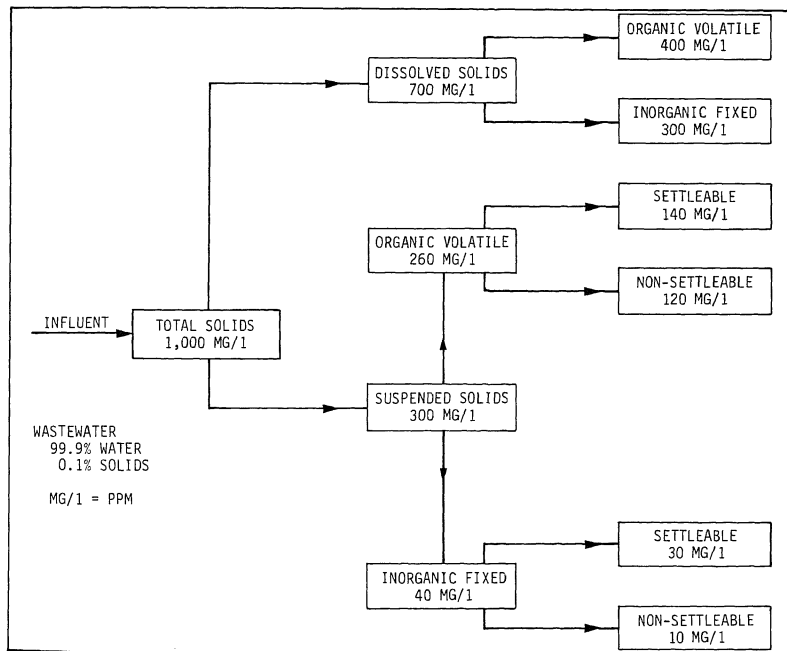
CHEMICAL CHARACTERISTICS

The chemical characteristics of wastewater of special concern to the Utilitiesman are pH, DO (dissolved oxygen), oxygen demand, nutrients, and toxic substances.

pH

The term *pH* is used to describe the acid or base properties of water solutions. A scale from

Table 10-4.—Solids of a Typical Domestic Wastewater



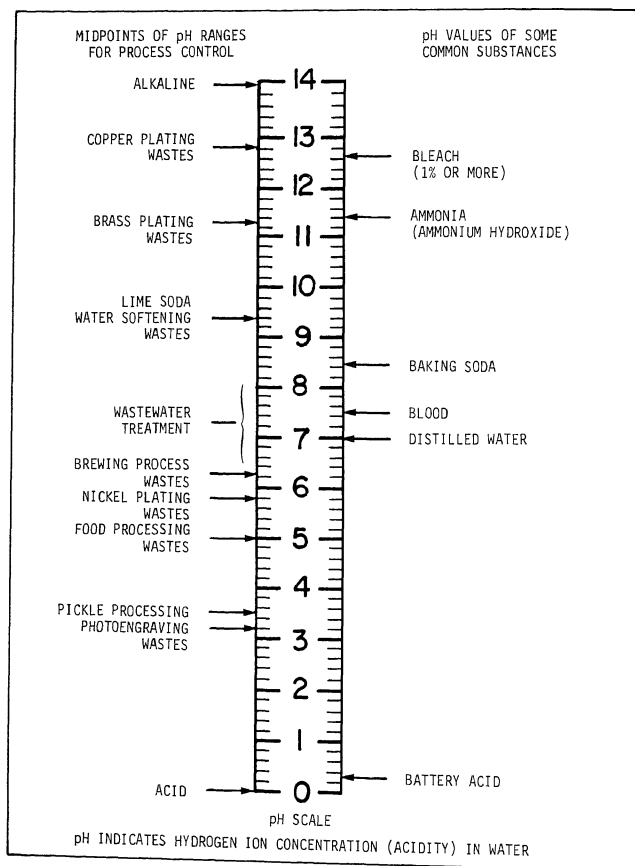
0 to 14 has been established where pH 7 is neutral. A pH less than 7 is considered acidic. A pH above 7 is considered alkaline or basic. Table 10-5 lists pH values for some common materials. A pH less than 7 in the wastewater plant influent may indicate septic conditions of wastewater. The pH values less than 5 and more than 10 usually indicate industrial-type wastes not compatible

with biological wastewater operations. Pretreatment of these wastes at the source is usually required since extreme pH values may damage biological treatment units.

Dissolved Oxygen

Dissolved oxygen (DO) in wastewater has a great effect on the waste's characteristics.

Table 10-5.—Common Substance pH Values



Wastewater that has DO is called *aerobic* or fresh. Aerobic raw sewage is usually gray in color and has a musty odor.

Wastewater that has no DO is called *anaerobic* or septic. Anaerobic raw sewage is usually black and has an offensive hydrogen sulfide or rotten egg odor.

Oxygen Demand

Oxygen demand is the amount of oxygen used by bacteria and other wastewater organisms as they feed upon the organic solids in the wastewater. Chemical tests such as the BOD (biochemical oxygen demand), the COD (chemical oxygen demand), the ODI (instantaneous oxygen demand or oxygen demand index), and the TOC (total organic carbon) measure the "strength" of sewage. These tests are discussed in detail later in this chapter. It is important that organic wastes be removed to protect the receiving body of water into which the wastewater plant is discharging.

Sludge deposits, odors, and fish kills may occur if removal is not adequate.

Nutrients

Nutrients are life-supporting nitrogen and phosphorus. They stimulate excessive growths of algae and other aquatic plant life. They are always present in domestic wastewaters and are not removed during conventional primary and secondary treatment. Removal is accomplished by processes in addition to normal wastewater treatment or tertiary treatment, when specific reuse requirements require it.

Toxic Chemicals

Most military and industrial installations use various types of toxic chemicals, the discharges of which can be harmful to wastewater treatment processes. These toxic chemicals should be pretreated or removed before the wastewater enters the collecting system. Table 10-6

Table 10-6.—Chemicals and Discharges Commonly Found at Military Installations

Physical	Chemical	Biological
Solids from:	Heavy Metals (in solution)	Bacteria—Fecal Coliforms
Paint	Chromium, Nickel, Lead	Iron and Sulfur Bacteria
Photo Lab	Zinc, Copper, Iron Oxide	Special Slimes, Fungi, and
Sandblasting	Chlorine, Aluminum, Mercury	Oil Related Growth
Grease—Valve, etc.	Cyanides	Algae—Green and Blue-green
(oils)	Phenols	Snails and Clams
Cutting Oils	Acids—Sulfuric, Hydrochloric, Nitric	Viruses
Heavy Metals—Cr(OH) ₃	(H ₂ SO ₄) (HCL) (HNO ₃)	
Rust (Oil)	Base—Caustic Soda (NaOH)	
Fiber—(Bacterial Slime)	Lime—Ca(OH) ₂	
Misc. Solids (Trash)	Quick Lime—CaO	
Grit—Rocks—Sand	Salts—Alum	
Color—Dyes	Brine—Sodium Chloride (NaCl)	
H ₂ S—Metal Sulfides	Copper Sulfate	
	Ship Chemicals—Cleaning	
	Gases—SO ₂ (H ₂ S)	
	Cl ₂	
	Ozone—O ₃	
	Pesticides—Soln (Solid Waste)	
	Germicides	
	Solvents—Refrigerants	
	Ketones	
	Ethylene Glycol Diethyl Ether	
	Detergents	
	Adhesives and Resins	
	Grinding and Polishing Compounds	
	Carbon—Spent	
	Bentonite and Coagulant Aids (Clays)	
	Polymers	
	Polyelectrolytes	
	Diatomaceous Earth	
	Iron Chlorides, Ferric and Ferrous	
	Chlorides or Sulfates	

lists several examples of these types of wastes.

BIOLOGICAL CHARACTERISTICS

The three biological organisms present in wastewater are bacteria, viruses, and parasites.

Bacteria

Sewage consists of vast quantities of bacteria, most of which are harmless to man. However, pathogenic (disease-causing) organisms such as typhoid, dysentery, and other intestinal disorders may be present in wastewater. Tests for total coliform and fecal coliform nonpathogenic bacteria are used to indicate the presence of pathogenic bacteria. Because it is easier to test for coliforms, fecal coliform testing has been accepted as the best indicator of fecal contamination. Fecal coliform counts of 100 million per 100 milliliters may be found in raw domestic sewage. Detectable health effects have been found at levels of 2,300 to 2,400 total coliforms per 100 milliliters in recreational waters. Disinfection, usually chlorination, is generally used to reduce these pathogens. Breakdown or malfunctions of chlorination equipment will probably result in excessive discharge of pathogenic organisms and can seriously affect public health.

Bacteria can also be classified according to their dissolved oxygen requirement. Aerobic bacteria are bacteria that require dissolved oxygen to live. Anaerobic bacteria cannot live if dissolved oxygen is present. *Facultative* bacteria can live with or without dissolved oxygen.

Viruses

Wastewater often contains viruses that may produce diseases. Outbreaks of infectious hepatitis have been traced through water systems because of wastewater entering the supply. Coagulation, sedimentation, filtration, and disinfection, if used efficiently, usually provide acceptable virus removal.

Parasites

There are also many species of parasites carried by wastewater. The life cycle of each is peculiar to the given parasite. Some are dangerous

to man and livestock, particularly during certain stages of the life cycle. Amoebic dysentery is a common disease caused by amoebic parasites. Chlorination, chemical precipitation, sedimentation, or sand filtration is used to ensure protection against parasites.

SEWAGE SAMPLING

Samples of sewage are taken to find out how well a treatment plant is working and what operating changes may need to be made. Some samples show how much the plant is reducing pollutants like BOD, solids, and so forth. Raw sewage entering the plant must be tested as well as the effluent from the plant and the receiving stream above and below the discharge point to determine how well the plant is removing pollutants. Since wastewater flows often change a great deal, daily sampling is suggested.

REPRESENTATIVE SAMPLING

A sample should be taken in a way that will represent the wastewater being treated. No matter how good the lab analysis is, if the sample was not correctly collected, the lab data will not be correct. With the large changes in composition and flow rate, getting a representative sample can be very hard. Careful thought, planning, and training must be used to develop and carry out a good sampling program.

Samples may be taken by hand or automatically. Taking samples by hand may be as simple as tying an open bottle to a pole that can be lowered into the wastewater. Table 10-7 explains some of the things that should be done when taking samples by hand. The automatic samplers may be made by the operator or bought.

GRAB SAMPLING

A grab sample is a single sample of wastewater taken over a short span of time, usually less than 15 minutes. This type of sample yields data about the wastewater at one time and place. The grab sample should be used where the wastewater does not change suddenly or change a great deal. For example, grab samples may be used to determine pH and temperature. Grab

Table 10-7.—Procedures for Manual Wastewater Sample Collection

Procedures	Special Cautions
1. Samples should be taken where wastewater is well mixed.	1. Weirs are not good sampling points since settling of solids is enhanced upstream and greases and oils build up downstream from the weir.
2. Sampling should be done in the center of the flow channel. To avoid floating scum, the mouth of the container should be held below the liquid surface.	2. Solids often build up near the sides and bottom of the flow channel.
3. A representative sample should be taken.	3. Raw wastewater should be sampled after screening and grit removal. Deposits or nonrepresentative materials such as grease or scum should be excluded from the sample. Particles larger than 0.25 inch (6 mm) in diameter should be excluded.
4. When compositing samples into other containers, the contents of each should be well mixed before pouring.	4. If dissolved gases or volatile substances are to be tested, turbulence may be produced by gentle stirring.
5. The sampling containers and sampling devices should be clean, uncontaminated, and suitable for the planned analysis.	5. Before the sample is taken, the container should be rinsed several times with the wastewater.
6. Sampling places should be easy to reach and safety precautions should be observed.	6. Proper sampling equipment should be available.

samples are also used when a batch dump or sludge discharge is seen.

COMPOSITE SAMPLES

A composite sample yields data about the wastewater over a longer span of time. A series of grab samples may be taken over a certain amount of time and combined to form a composite sample. These samples should show the time and frequency of the sample; for example, an 8-hour composite of 30-minute grab samples. The composite sample is used to find BOD, COD, suspended solids, and nutrients.

FLOW-PROPORTIONAL SAMPLES

The composite may be flow proportional. For this type of sample, the volume of the sample

changes in proportion to the flow. The flow-proportional composite sample is most often run for 24 hours with a 2-hour interval between each collection. To collect this kind of sample, the volume needed for the tests and the average daily flow for the plant must be known. Table 10-8 shows the volumes required for some tests. The following formula may be used to find the volume of sample to be taken at each interval.

$$\text{Liters required} = \frac{\text{Flow at sampling time}}{\text{Average flow}} \times \frac{\text{Total sample size}}{\text{Number of samples}}$$

For example, to collect an 8-hour composite sample with a 2-hour interval, five samples would be needed. If a total sample of 2 liters was needed, the average daily flow was 60,000 gallons (227 cubic meters), and the flow at the first sample time was 45,000 gallons per day (170 cubic meters),

Table 10-8.—Recommendation for Sample Volume and Preservation of Sample

Measurement	Type of Sample	Vol. Req. (ml)	Container	Preservative	Holding Time
Acidity	G*	100	P, G**	Cool, 4°C***	24 hr
Alkalinity	G	100	P, G	Cool, 4°C	24 hr
Arsenic	PC****	100	P, G	HNO ₃ to pH 2	6 mo
BOD	PC	1,000	P, G	Cool, 4°C	6 hr ¹
Bromide	G	100	P, G	Cool, 4°C	24 hr
COD	PC	50	P, G	H ₂ SO ₄ to pH 2	7 days
Chloride	G	50	P, G	None req.	7 days
Chlorine	G	50	P, G	Cool, 4°C	24 hr
Color	G	50	P, G	Cool, 4°C	24 hr
Cyanides	G	500	P, G	Cool, 4°C NaOH to pH 12	24 hr
Dissolved Oxygen					
Probe	G	300	G only	Det. on site	No holding
Winkler	G	300	G only	Fix on site	No holding
Fluoride	G	300	P, G	Cool, 4°C	7 days
Hardness	G	100	P, G	Cool, 4°C	7 days
Iodine	G	100	P, G	Cool, 4°C	24 hr
MBAS	G	250	P, G	Cool, 4°C	24 hr
Metals					
Dissolved	PC	200	P, G	Filter on site HNO ₃ to pH 2	6 mo
Suspended	PC			Filter on site	6 mo
Total	PC	1,100		HNO ₃ to pH 2	6 mo
Mercury					
Dissolved	PC	100	P, G	Filter HNO ₃ to pH 2	38 days (glass) 13 days (hard plastic)

Table 10-8.—Recommendation for Sample Volume and Preservation of Sample—Continued

Measurement	Type of Sample	Vol. Req. (ml)	Container	Preservative	Holding Time
Nitrogen					
Ammonia	G	400	P, G	Cool, 4°C H ₂ SO ₄ to pH 2	24 hr ²
Kjeldahl	PC	500	P, G	Cool, 4°C H ₂ SO ₄ to pH 2	24 hr ²
Nitrate	PC	100	P, G	Cool, 4°C H ₂ SO ₄ to pH 2	24 hr ²
Nitrate	G	50	P, G	Cool, 4°C	24 hr ²
NTA	PC	50	P, B	Cool, 4°C	24 hr
Oil & Grease	PC	1,000	G only	Cool, 4°C H ₂ SO ₄ to pH 2	24 hr
Organic Carbon	PC	25	P, G	Cool, 4°C H ₂ SO ₄ to pH 2	24 hr
pH	G	25	P, G	Cool, 4°C Det. on site	6 hr ¹
Phenolics	G	500	G only	Cool, 4°C H ₃ PO ₄ to pH 4 1.0 g CuSO ₄ /l	24 hr
Phosphorus					
Ortho-phosphate, dissolved	G	50	P, G	Filter on site Cool, 4°C	24 hr ²
Hydrolyzable	G	50	P, G	Cool, 4°C H ₂ SO ₄ to pH 2	24 hr ²
Total	PC	50	P, G	Cool, 4°C	24 hr ²
Total, dissolved	PC	50	P, G	Filter on site Cool, 4°C	24 hr ²
Residue					
Filterable	PC	100	P, G	Cool, 4°C	7 days
Nonfilterable	PC	100	P, G	Cool, 4°C	7 days
Total	PC	100	P, G	Cool, 4°C	7 days
Volatile	PC	100	P, G	Cool, 4°C	7 days

Table 10-8.—Recommendation for Sample Volume and Preservation of Sample—Continued

Measurement	Type of Sample	Vol. Req. (ml)	Container	Preservative	Holding Time
Settleable Matter	PC	1,000	P, G	None req.	24 hr
Selenium	PC	50	P, G	HNO ₃ to pH 2	6 mo
Silica	PC	50	P only	Cool, 4°C	7 days
Specific Conductance	G	100	P, G	Cool, 4°C	24 hr ³
Sulfate	PC	50	P, G	Cool, 4°C	7 days
Sulfide	G	50	P, G	2 ml zinc acetate	24 hr
Temperature	G	1,000	P, G	Det. on site	No holding
Threshold Odor	G	200	G only	Cool, 4°C	24 hr
Turbidity	G	1,000	P, G	Cool, 4°C	7 days

*Type G sample = Grab. **P, G = Plastic or Glass.
 4°C = 4 Celsius. *PC = Proportional Composite.

¹If samples cannot be returned to the lab in less than 6 hours and holding time exceeds this limit, the final reported data should show the actual holding time.

²Mercuric chloride may be used as an alternate preservative at a concentration of 40 mg/l, especially if a longer holding time is required. However, mercuric chloride should not be used if something better is available.

³If the sample is stabilized by cooling, it should be warmed to 25°C for reading, or temperature correction made and results reported at 25°C.

Note: It has been shown that certain samples properly preserved may be held beyond the recommended holding time. Consult designated authority.

then the milliliters required for the first sample could be figured like this:

$$\text{Liters required} = \frac{45,000 \text{ gal/day}}{60,000 \text{ gal/day}} \times \frac{2 \text{ liters}}{5 \text{ samples}}$$

$$\text{Liters required} = \frac{170 \text{ cubic meter/day}}{227 \text{ cubic meter/day}} \times \frac{2 \text{ liters}}{5 \text{ samples}}$$

$$\text{Liters required} = .30$$

$$\text{Milliliters required} = 300$$

$$\text{NOTE: } 264 \text{ gallons} = 1 \text{ cubic meter (m}^3\text{)}$$

$$\text{Gallons} \times 0.003785 = \text{cubic meters (m}^3\text{)}$$

$$1 \text{ liter} = 1,000 \text{ milliliters}$$

SAMPLE STOWAGE

To get the best results, samples should be analyzed as soon as possible after they are collected. Some tests, such as DO, temperature, and pH must be performed at the time of collection since the results can change while the sample is being carried to the lab. Some other tests may be delayed if the sample is properly stored. The most common means of preserving a sample is to cool it to 2°C to 10°C. Table 10-8 shows some ways to preserve the sample.

Table 10-9.—Important Laboratory Tests

Test to be Performed	Sampling Point	Recommended Means of Collection	Recommended Frequency of Collection
Settleable Solids	1. Influent 2. Final effluent	Grab or Composite	Daily
Suspended Solids	1. Influent 2. Final effluent	Proportional Composite	Weekly Weekly
BOD ₅ or COD	1. Influent 2. Effluent 3. Stream—above & below discharge	Proportional Composite	Weekly
Dissolved Oxygen	1. Influent 2. Final effluent 3. Stream—above & below discharge	Grab	Daily
pH	-----	Grab	Daily
Fecal Coliform	Final Effluent	Grab	Weekly
Alkalinity	1. Final effluent 2. Digester	Proportional Composite or Grab	Daily
Chlorine Residual	Final effluent	Grab	Daily (at least)

IDENTIFYING SAMPLES

After the sample is collected, it should be identified with a label. The label should include the following information:

- Where the sample was taken
- The date and time of collection
- The type of sample (grab or composite with the appropriate time and volume information)
- Anything that might change before laboratory testing such as temperature, pH, and appearance

- The initials or name of the person who took the sample

SEWAGE TESTING

Laboratory reports are useful in the operation of a wastewater treatment plant. The operator can use laboratory test results to keep the plant working at its best and to give early warning of operating problems. Laboratory testing programs vary with the type of treatment, size of the plant, local water quality requirements, and the NPDES permit requirements. Some of the most common laboratory tests for wastewater treatment plants are shown in table 10-9. They are discussed later in this chapter. Laboratory tests required by NPDES are determined for each treatment plant

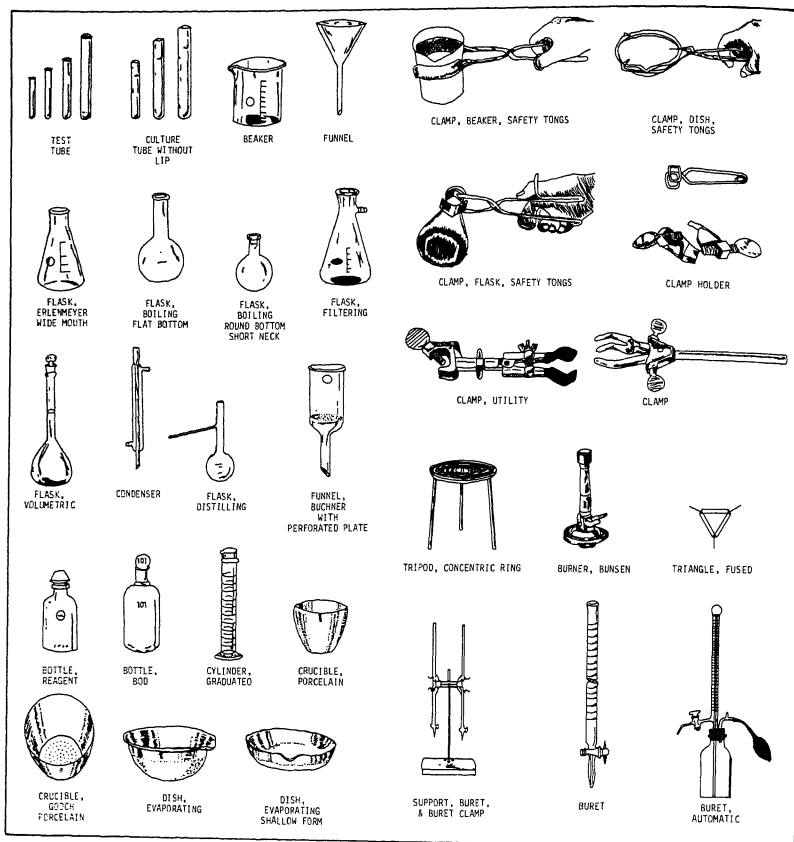


Figure 10-1.—Illustrations of laboratory apparatus.

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and are cited in the discharge permit. The normal procedures for these tests are given in the *Standard Methods for the Examination of Water and Wastewaters* and the *Methods of Chemical Analysis of Water and Wastes* published by the EPA.

LABORATORY EQUIPMENT

Examples of the various types of laboratory equipment are shown in figure 10-1. In order for

the operator to conduct accurate sewage tests, the laboratory must be equipped with a minimum of equipment. Table 10-10 lists the types of equipment needed for some of the basic laboratory tests.

The operator should always maintain this equipment in a high state of repair and cleanliness. Any contamination of the test equipment may adversely affect the results. Refer to the

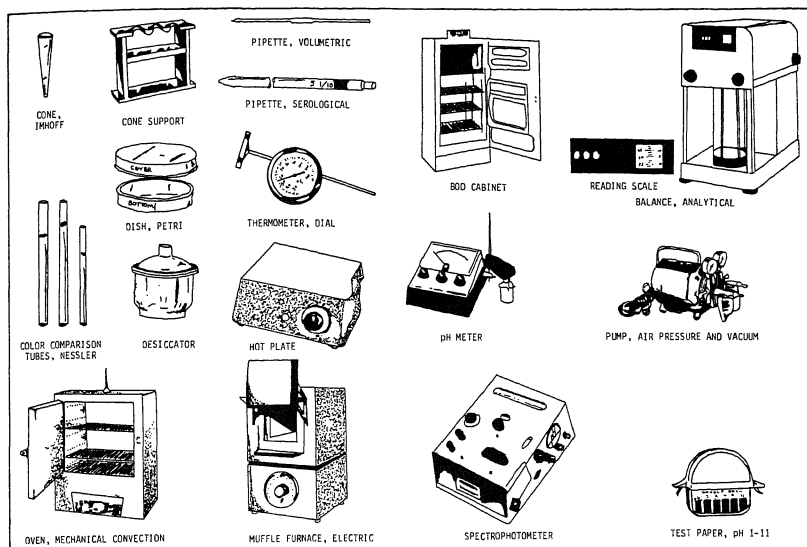


Figure 10-1.—Illustrations of laboratory apparatus—Continued.

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manufacturer's instructions for the proper maintenance procedures for each piece of equipment. Table 10-11 gives some basic guidelines for the maintenance and use of various types of laboratory equipment.

Safety should be vital to all personnel conducting sewage tests. Good housekeeping is essential in a laboratory to prevent mishaps and damage to expensive equipment. Each piece of equipment should be cleaned and returned to its proper place after being used.

When conducting sewage tests, it is always wise for the operator to avoid actual contact of the hands with the sewage samples or other filth. Hands must be kept out of the nose, mouth, and eyes. It is particularly important to use gloves when the hands are chapped, or burned, or the skin is broken from any wound. Operators should thoroughly wash their hands with plenty of soap and hot water before eating.

DISSOLVED OXYGEN TEST

The DO test finds the milligrams per liter (mg/l) of oxygen that is dissolved in water or wastewater. Oxygen exists as a gas and can dissolve in water in only a limited amount. Pure water at 20 °C at sea level can hold a maximum of 9.17 mg/l of DO. Raising the temperature, salt content, or altitude will lower the DO level in the water. An important thing to remember is that this test should be run as soon as possible after the sample is taken. It must always be run as a grab sample. It is best to test several samples taken at different times during the day because the DO content of wastewater may vary. If incoming wastewater has no DO, it is septic. Most wastewater treatment plants are not built to treat septic wastewater. A great deal of plant and animal life that lives in water and wastewater, including necessary microorganisms, needs DO just as we need oxygen from the air. If the DO is used up, aerobic organisms will die and the water will become anaerobic or septic and foul

Table 10-10.—Types of Equipment Needed for Various Laboratory Tests

CONSTITUENTS TO BE ANALYZED	EQUIPMENT NEEDED*					
	Atomic Absorption 600°C Muffle Furnace 103°C Drying Oven Analytical Balance Imhoff Cone	pH Meter Lamotte Kit BOD Incubator Vacuum Pump Hot Plate Kjeldahl Unit	Condenser/Extract. Eq. DO Meter & Probe Autoclave Amperometric Titrat.	35°C Incubator Gas Analyzer Steam Bath Magnetic Stirrer Blender	Turbidity Meter Carb. Adsorp. Unit Desiccator Spectrophotometer Stirring Equip.	Vibrating Shaker Total Org. Carb. Analy Purity Meter Water Still
Volatile Solids	o o o				o	
Total Solids	o o				o	
Settleable Solids	o					
pH		o				
Total Sulfides		o				
BOD		o				o o
COD		o	o	o		o o
Suspended Solids	o o	o			o	
Dissolved Oxygen			o			
Chlorine Residual			o			
MPN Coliform**						
Volatile Acids		o	o			o o
Alkalinity		o		o		
Gas Analysis				o		
Grease	o o	o o	o	o		
Total Organic Carb.						o
Turbidity					o	
Volatile SS	o o o	o			o	
Total Phosphorus		o				
MBAS***					o	
Sludge Filterability		o o				
Ash Analysis	o o					
Jar Test					o	
Apparent Density	o					o
Isotherms	o o	o			o	o
Calcium Content	o				o	
Ammonia Nitrogen		o	o			
Organic Nitrogen		o o	o			
Nitrate Nitrogen					o	
Heavy Metals	o					

*The equipment needed is subject to plant size and complexity of processes and the degree of control required.

**MPN = Most probably number

***Methylene Blue Active Substance

Table 10-11.—Maintenance Guide

Equipment	Function	Used for	Instructions*
ANALYTICAL BALANCE	Precision weighing.	Preparation of standards. Weighing samples of total and suspended solids, sludge moisture, oils, and grease.	Install on heavy shockproof table away from vibration and extreme temperature variations. Keep level at all times.
TRIP BALANCE	Course weighing.	Weighing samples of MLSS, wet sludge filter cake, grit, and chemicals.	Maintain and use according to manufacturer's instructions.
pH METER	pH measuring.	Analysis of wastewater, industrial waste, and determining endpoints of alkalinity, acidity and ammonia tests, also streams, surface water, and various solutions.	Calibrate frequently with buffers at pH 4.0, 7.0, and 10.0. Be sure buffers are fresh. Immerse electrodes in distilled water while not in use. Discard electrodes with broken tips and deep scratches. Keep electrode reservoir filled. Rinse electrodes with distilled water after each operation. Keep sample mixed during test. Observe temperature of sample and adjust meter.
DRYING OVEN	Controlling drying of samples and glassware.	Drying samples suspended and dissolved solids and sludge. Also drying chemicals and glassware.	Equip with accurate thermometer. Be sure temperature controls are working properly. Keep doors fitting tight to prevent heat loss. Clean the oven frequently. Arrange samples to prevent cross-contamination. Locate away from heat-sensitive equipment.

*Always follow manufacturer's instructions for maintenance and operation.

Table 10-11.—Maintenance Guide—Continued

Equipment	Function	Used for	Instructions*
MUFFLE FURNACE	Igniting (burning) volatile substances.	Determining amount of volatile and fixed solids in suspended, total, activated, and digester solids and/or sludge samples. Igniting barium sulfate precipitates in sulfate testing.	Be sure the furnace is equipped with an accurate temperature control. Keep heat chamber clean. Check frequently for deposits of soot and ash. Be sure that fumes are properly exhausted. Locate away from heat-sensitive equipment.
DESICCATOR	Providing moisture-free atmosphere for temporary storage of glassware, chemicals, and samples.	Drying chemical powders. Cooling glassware and samples before reweighing.	Check doors or lids for tight seal. Keep closed at all times except when inserting or removing materials. Be sure desiccant material is active. Replace or replenish inactive desiccant.
BOD INCUBATOR	Providing constant light-free temperature for BOD samples.	Incubating BOD samples at 20°C for 5 days.	Check temperature controls for accuracy. Be sure proper temperature is maintained at all times. Be sure door closes and seals properly. Keep chamber clean and free of biological growths.
WATER DISTILLATION UNIT	Distilling water to laboratory standards.	Providing high-quality water for chemical solutions, BOD dilution, bacteriological and chemical analyses. Also water for rinsing analytical glassware.	Check temperature control for accuracy. Be sure boiler, condenser coils, and tubing are free of deposits and scale. Clean frequently. Use borosilicate glass storage containers with tight covers to exclude airborne dust, gases, and organisms. Test pH and conductivity frequently to help ensure purity.

*Always follow manufacturer's instructions for maintenance and operation.

Table 10-11.—Maintenance Guide—Continued

Equipment	Function	Used for	Instructions*
DEIONIZER	Purifying water by ion exchange rather than by distillation.	Same as for water distillation unit.	Use ion exchange cartridges of proper type. Discard cartridges at once when exchange capacity is exhausted. Be sure water feed rate is not exceeded. Store deionized water same as distilled water.
COLORIMETER OR SPECTROPHOTOMETER	Quantitatively measuring water quality by colorimetric method.	Testing for phosphorus, nitrate, nitrite, hexavalent chrome, color, sulfate by turbidity method, phenols, residual chlorine, and others.	This equipment is delicate. Handle with care. Keep adequate stock of replacement parts. Be sure the equipment is properly calibrated before use for transmittance or absorbance readings. Be sure to use proper filter for test being performed.
REFRIGERATOR	Low temperature storage	Storage of wastewater and sludge samples at 4°C. Also storage of unstable chemicals.	Check temperature controls for accuracy. Keep interior clean and free of biological growths. Provide refrigerator(s) with adequate capacity for laboratory needs.
AUTOCLAVE	Sterilization by steam.	Sterilization of dilution water, glassware, sample media, and related items for bacteriological testing.	Check time, temperature, and pressure controls for accuracy. Confirm sterilization by use of test strips or other indicators. Be sure sterilized materials are properly wrapped, sealed, and stored to prevent contamination.

*Always follow manufacturer's instructions for maintenance and operation.

Table 10-11.—Maintenance Guide—Continued

Equipment	Function	Used for	Instructions*
HOTPLATE OR HEATER	Heating liquids and solids	Preparing analytical solutions. For evaporation concentration, hydrolysis digestion, and other analytical operations.	Check temperature controls for accuracy. Be sure units are adequate for laboratory needs. If controls are manual, do not leave hotplates unattended.
DISSOLVED OXYGEN ANALYZER	Instrumental measuring of dissolved oxygen.	Testing wastewater, industrial waste, streams, and BOD samples for dissolved oxygen.	Check accuracy of instrument frequently. Recalibrate, if necessary, using approved standards. Store probe in water or in moisture-saturated air. Keep probes clean. Change membranes and replace electrolyte as recommended by manufacturer.
BACTERIA INCUBATOR	Providing constant temperature during incubation of samples.	Coliform and other bacteriological tests.	Check accuracy of temperature controls. Keep storage chamber clean and free of spillage and bacteriological growths. Check door(s) for proper closing and sealing. Locate unit where not exposed to extreme temperature changes.
WATER BATH INCUBATOR	Providing constant temperature for water bath incubation of sample.	Testing coliform and nitrate samples. Also digestion of wastewater samples.	Check accuracy of temperature controls. Keep storage chamber clean and free of rust, scale, and sediment. Check cover and seal for proper fit. Maintain bath water at correct level.

*Always follow manufacturer's instructions for maintenance and operation.

Table 10-11.—Maintenance Guide—Continued

Equipment	Function	Used for	Instructions*
CONDUCTIVITY METER	Measuring electrical conductance/resistance of a solution.	Testing distilled water, water, and wastewater samples.	Calibrate frequently against known reference. Keep electrode clean and stored in distilled water between tests. Observe between tests. Observe sample temperature and make necessary adjustment.
TOTAL ORGANIC CARBON ANALYZER	Analyzing carbon fractions by combustion/infrared methods.	Rapid analysis of total inorganic and organic carbon in water and wastewater samples.	Due to the complexity of this unit, problems should be referred to specially trained technicians.
ATOMIC ABSORPTION SPECTROPHOTOMETER	Analyzing metal ions by atomic absorption/emission method.	Testing samples for heavy metal or toxic metal ions.	Be sure the unit is properly installed with fume exhaust system. Problems with the unit should be referred to a specially trained technician.

*Always follow manufacturer's instructions for maintenance and operation.

odors will develop. If this occurs, you should check for flow problems within the sanitary system upstream of the treatment plant.

HYDROGEN ION CONCENTRATION (pH VALUE) TEST

The measure of acidity or basicity (alkalinity) of something is called the pH. The effect of pH on some parts of wastewater treatment makes it an important test. A low pH of domestic wastewater may mean that the wastewater is septic, or it can mean that industrial or commercial acid wastes are entering the system. A pH of 6.5 to 8 is about right for treatment plant influent. Test results showing a very high or low pH may mean someone is breaking sewer use regulations. Sudden changes of 0.5 or more on the pH scale may mean that operating problems are starting. Grab samples should be taken for pH tests.

SETTLABLE SOLIDS TEST

The settleable solids test on wastewater can tell the operator a lot about what kind of wastewater is coming into the plant and how the solids are settling. Also, the settleable solids test can help the operator estimate the volume of sludge to be expected in the clarifier.

Either grab or composite samples will work for this test. The test is done using an Imhoff cone. The Imhoff cone (fig. 10-1) can be either glass or plastic. It can hold 1 liter and is marked off in milliliters (ml).

Before running the test, you should allow the sample to settle for 45 minutes. After 45 minutes, you should run a glass or plastic rod gently down the inside of the cone and turn it to loosen solids clinging to the sides. Settling should then continue for another 15 minutes. The depth of the solids in the bottom is then read from the scale and recorded as milliliters of settleable solids per liter of wastewater.

ACTIVATED SLUDGE SETTLABILITY TEST

The settleability test is often used with all kinds of activated sludge plants to find the amount of solids in aeration units. The results help the operator to decide when to waste sludge and to find the rate of sludge return. The activated sludge settleability test can be run in a 1,000 ml graduated cylinder or in any clear, widemouthed container. The container should be ruled off into 10 units

such as centimeters, milliliters, or inches. The sample is poured into the cylinder or jar up to the top mark and allowed to settle. Readings are taken from time to time to find settling rates. The sample should be allowed to settle for about 30 minutes.

FIVE-DAY BIOCHEMICAL OXYGEN DEMAND (BOD₅) TEST

The BOD₅ test is the most important test for finding the polluting strength of a wastewater. It is the most widely used way to check how the treatment plant is running. The BOD₅ test indirectly measures the amount of organic material in the sample. Either grab or composite samples may be used for this test.

NPDES permits often state that influent and effluent *flow-proportional* composite samples be taken for the BOD₅ test. Normal domestic wastewater coming into the plant should be in a 200 to 300 mg/l BOD₅ range. The effluent must comply with the plant's NPDES permit.

To run the test, the amount of oxygen is measured in a portion of diluted wastewater, and another portion like the first one is stored at 20°C for 5 days. The glass bottles shown in figure 10-1 are used for this test. During the 5 days, the microorganisms eat the organic matter in the wastewater and use oxygen at the same time. At the end of 5 days, the amount of oxygen consumed by the microorganisms times the dilution factor of the sample gives the sample's 5-day BOD. The dilution factor is the number of milliliters of dilution water added to a given number of milliliters of sample.

CHEMICAL OXYGEN DEMAND (COD) TEST

Like the BOD₅ test, the chemical oxygen demand (COD) test finds the amount of oxygen required to consume the organic matter in a wastewater sample. The COD test does not measure the amount of oxygen used by the microorganisms. It uses a strong, chemical concentrated sulfuric acid silver sulfate solution. It is a good operating control test because the results can be obtained in as little as 1 hour. COD test results are equal to or greater than BOD₅ test results. The chemical used in the COD test attacks more organisms in the wastewater than the slower BOD₅ organisms. BOD₅ data can often be related to COD data by a multiplying factor. For instance, the 200 to 300 mg/l BOD₅ of normal

wastewater influent is about two-thirds of its usual 300 to 450 mg/l COD value. If such a factor can be figured for a certain kind of wastewater, COD data can be used to predict BOD 5 test results that will not be known for 5 days.

TOTAL SUSPENDED SOLIDS TEST

Total suspended solids are those solids in wastewater that can be taken out with a filter having a specified pore size. Suspended solids are made up of settleable solids and nonsettleable solids. Suspended solids tests can be run with either grab or composite samples, but flow-proportional composite samples are the best for this test. Influent wastewater may have as much as 400 mg/l of suspended solids.

MIXED LIQUOR SUSPENDED SOLIDS (MLSS) TEST

The suspended solids test that is run on the aeration tank mixed liquor is called the mixed liquor suspended solids test or MLSS test. It is used as a control test to help find out whether to increase or decrease the rate of sludge return and when to waste sludge. The very high solids content of mixed liquor requires a larger diameter filter (11 centimeters instead of 2.4 centimeters) to prevent rapid clogging.

CHLORINE RESIDUAL TEST

When chlorine is used to disinfect the effluent, tests are needed to see if the chlorine residual requirement has been met. The chlorine residual test may be run using the *iodometric* or *amperometric* methods. Since grab samples are used for these tests, most states suggest that the test be run within 30 minutes after taking the sample.

FECAL COLIFORM TEST

The fecal coliform test is an indicator of harmful bacteria in the wastewater. Both the membrane filter and most probable number (MPN) can be used to run the test. If the sample is not prepared for the test on the site, it should be cooled to 4°C within 30 minutes and then tested within 6 hours.

ALKALINITY

The alkalinity test can tell the operator a lot about the wastewater in the plant. A very high

alkalinity in the wastewater may mean that an alkaline industrial waste has entered the system. The alkalinity test is often used to see how the anaerobic sludge digesters are working. The alkalinity in treatment lagoons usually goes down as the lagoon becomes septic. The alkalinity usually shows a 20 to 30 mg/l change before there is a change in pH.

LABORATORY RECORDS

Records can be used to find the best operating controls for a wastewater plant, problems that might arise in the plant, and the future needs of the plant. Records may also be used in court if a lawsuit is filed against the treatment plant.

The treatment plant should keep three kinds of records. These three types are physical records that describe in detail all areas of the plant itself, maintenance records that show what repair and cleaning has been done or needs to be done, and performance records that show the plant's operating data.

Physical records include operation and maintenance (O&M) manuals, actual plans and blueprints for the plant, shop drawings, O&M guides from equipment manufacturers, costs for all units, a hydraulic profile showing the height of water in all treatment units, and an equipment record. Under Public Law (PL) 92-500, consulting engineers are required to provide operation and maintenance (O&M) manuals for the treatment plants they design. These O&M manuals must meet the requirements of *Considerations for Preparation of Operation and Maintenance Manuals*, EPA, Washington, D.C., 1974.

Preventive maintenance in the treatment plant can reduce costly repairs and downtime on equipment. One of the key steps in a good maintenance program is keeping records. These records include the data needed to make a maintenance schedule, to estimate a maintenance budget, and to build up enough spare parts.

A record of all equipment in the plant must be made. This can be done on index cards. Each piece of equipment should be given a number based on where it is located in the plant. This number is written on an index card with the name of the equipment, where it is located in the plant, the name and address of the manufacturer or supplier, the cost, and when it was installed. The card should also have the type, model, serial, and any other code numbers, along with the capacity or size rating. The same card or another set of cards should include the type of maintenance

required and how often it is needed; the special lubricants or coatings needed; and a record of all work done on the unit, including the labor, parts, and total cost. This data should be considered when planning to buy new equipment and making a maintenance schedule.

Making a maintenance schedule requires careful thought. Good records can serve as a guide. Some large treatment plants now use a computer to plan maintenance schedules and keep records up-to-date. Preventive maintenance should be scheduled so it can be done during good weather and not during times of peak load at the plant. Also, the schedule must leave time for repair work. A large chart showing what needs to be done daily, weekly, monthly, quarterly, semiannually, and annually can help in setting up a work schedule.

A spare parts inventory should be established. Many spare parts must be ordered several days or weeks before they are delivered. These spare parts should be stocked at the treatment plant so the plant won't have to be shut down until the part arrives. A list or inventory of spare parts makes reordering simpler. A written record of parts used and replaced should be kept. The operator should record the date an item was ordered, the date delivered, its cost, and the name of the supplier, each time a part is ordered and delivered.

In addition to the above records you must also maintain performance records. There are three types of performance records. These are the laboratory records, operator's log, and NPDES forms.

A complete set of laboratory records should be kept for all laboratory tests. The laboratory record should have the date and time the sample

was taken, the method used to take the sample, the name of the person who took the sample, where the sample was taken, the test performed on the sample, and the results of the laboratory test. These records should be kept in a bound notebook so they can be used as a part of legal testimony about the operation of the plant if need be. A monthly or quarterly report is also required at most plants.

A monthly report is required for all wastewater plants on a military installation. Since no two treatment plants are exactly the same, the operator will find that a special log designed for the treatment plant is helpful. The operator should report on special features of the treatment plant under the blank columns in the log. Operators at each treatment plant are required to complete the log. Navy plant operators use the Wastewater Treatment Plant Operating Record, NAVFAC 11340/1 (6-75).

Finally, every treatment plant that discharges to a body of water must get an NPDES permit from the EPA or the designated state agency. The permit lists standards for the effluent, tests required, how often the tests must be run, and the sampling method of each test. The treatment plant must submit a monthly or quarterly report to the EPA or the designated state agency with all the laboratory tests required by the permit. These reports and laboratory records must be kept for at least 3 years.

Use performance records to check the plant. The performance records at a treatment plant can provide good process control data to the operator. Results of laboratory tests that differ a lot from previous records may show an equipment breakdown, an industrial waste discharge, or a break in the collection system. Table 10-12 shows

Table 10-12.—Variations in Performance and Some Common Causes

Variation	Possible Cause	Solution
BOD ₅ (or COD): Increase	Increased organic loading.	Identify source of increase. If overloading is permanent, adjust treatment plant processes for maximum efficiency. Require adequate pretreatment. Enforce sewer use regulations if violations are found. Install holding tanks (ponds) if feasible. Modify or expand treatment units.
	Population growth. Industrial expansion.	
	Septic influent.	
	Septic conditions in treatment plant units.	Freshen by aeration or chlorination.
		Check on detention time and sludge pumping schedule. See if dissolved oxygen requirements of aerated units are being met.

Table 10-12.—Variations in Performance and Some Common Causes

Variation	Possible Cause	Solution
BOD ₅ (or COD): Decrease	Decrease in organic loading.	No problem.
	Wastewater organisms killed by toxic waste.	Find source of toxic waste. Require neutralization or exclude from treatment facility by enforcing sewer use regulations. When toxic waste is found, immediately notify appropriate military and regulatory authorities. Immediately seek advice from qualified specialists as to disposal of toxic waste remaining in the plant. Disposal after neutralization and/or dilution may be no problem.
Suspended Solids: Increase	Industrial expansion or population increase. Changes in industrial processes.	Generally, same procedure as for BOD ₅ increase. Unless growth and expansion are the causes, check pretreatment for operation. Also check for industrial "dumping." Enforce sewer use regulations, if applicable.
Suspended Solids: Decrease	Collection sewers blocked (clogged).	Inspect, clean and flush if needed.
	Broken or completely blocked sewer resulting in bypassing.	Clean and flush sewer if clogged. Repair or replace if sewer is broken or settled out of position. If wastewater is bypassing, treat with chlorine at once.
pH: Increase	Industrial discharge. Inadequate pretreatment.	Try to find source of alkaline (basic) discharge and require pH adjustment before discharge to collection system. Check on operation of pretreatment units.
pH: Decrease	Industrial discharge. Inadequate pretreatment.	Try to find source of acidic discharge and proceed as suggested above.
	Septic influent.	Check sewers for low velocity (flat grades) and blockage (clogging). Clean and flush sewers. Chlorinate if necessary. Check lift station wet wells for proper detention time (not more than 30 minutes in warm weather). If the cause cannot be remedied, then freshen the septic wastewater at the head of the treatment plant by using aeration and/or chlorine. If the pH remains too low for satisfactory operation, adjust by applying alkaline chemical such as lime or soda ash.

Variation	Possible Cause	Solution
Wastewater Flow: Increase	Population and industrial expansion.	Consider installing holding ponds or tanks. Consult with industry to prevent "dumping" during high flow periods. If increased flow is expected to be continually above treatment plant design capacity, plant expansion and/or modifications should be considered.
	Infiltration-Inflow.	Check collection system for unauthorized storm and surface water connections. Enforce sewer use regulations. Repair or replace broken or cracked pipes and leaky joints. Raise or provide good surface drainage for manhole covers in low areas. Install holding ponds or tanks.
Wastewater Flow: Decrease	Bypassing leakage (ex-filtration).	Check collection system for leaks and bypassing. Make necessary repairs. Notify appropriate regulatory officials at once. Request their advice.
	Decreased water use.	Recirculate enough of the treatment plant effluent to primary clarifier, trickling filter (or other unit) to prevent excessive detention time and provide better operation.
Temperature Influent: Increase	Discharge of hot wastes.	Enforce sewer use regulations if temperature is high enough to hinder operation.
Temperature Influent: Decrease	Infiltration—inflow of storm water.	Locate points of entrance. Repair if needed. Enforce sewer use regulations, if applicable.
Chlorine Demand: Increase	Inefficient operation due to septic conditions, poor settling, and other operating problems.	Check on efficiency of each treatment unit. Adjust controls to secure maximum efficiency. Check sludge-pumping schedule and rate, recirculation of effluent, aeration rate, trickling filter operation, and return of digester supernatant. Check for proper detention time in clarifiers and aeration tanks.
	Industrial discharges. Slug loading or "dumping."	If possible, secure cooperation of industry in controlling time and rate of discharging strong waste.
	Chlorine feed equipment not properly working.	Check accuracy of dosing equipment. The problem could be improper dose instead of increased chlorine demand. Find out if chlorine and wastewater are being properly mixed.
	Temperature.	Wastewater with high temperature usually requires more chlorine to satisfy the chlorine demand.

some changes from normal values and some causes for these changes.

DISPOSING OF AND MONITORING SEWAGE EFFLUENTS

The wastewater treatment process includes taking the solids out of the wastewater, getting rid of the solids, and getting rid of the treated wastewater or effluent in a way the federal and state regulating agencies approve. Sludge handling and disposal are covered in chapter 13. This chapter describes many ways to dispose of plant effluent.

All plants that discharge an effluent must have NPDES permits issued by the EPA or by a state agency for the EPA. Before these permits are given to the plant, officials make a careful survey of the water use nearby that might be hurt by the effluent of the treatment plant. The permit may list top, bottom, or average limits for some kinds of pollutions. It may also state in what way the plant can dispose of its effluent. If the plant does not meet the limits on the permit, the operator should contact the regulating agency at once. The permit can be changed or revoked by the agency. Sometimes the plant may be allowed to discharge more than the limit on the permit, but that is up to the regulating agency. The purpose of the permit is to protect human health and natural resources. All operators should know the permit limits and make every effort to ensure that the treatment plant complies with them.

EFFLUENT DISCHARGE METHODS

The two major methods of discharging effluent are continuous discharge and intermittent discharge.

Most treatment plants discharge an effluent to a receiving water all the time. The effluent may go to an ocean, gulf, bay, lake, or stream. The point of discharge may be above or below the surface of the receiving water. *Continuous discharge* is often cheaper than other methods because it takes less manpower, equipment, and storage to operate. However, a very good monitoring program must be used to make sure toxic waste is not discharged. After a toxic waste is discharged, there is no practical way to stop or isolate the toxic substance.

Intermittent discharge means that the effluent is not discharged all the time, but only from time to time. This type of discharge requires a place

to store the effluent. It is not often used at large plants. But it does work well at lagoons and small treatment plants that have holding or "polishing" ponds.

Intermittent discharge lets the operator choose the time and rate of discharge. A controlled amount of effluent can usually be discharged without hurting the quality of the receiving water if the operator picks the right time for all discharges. In some cases, the receiving water has even been improved. Intermittent discharge may cost more to build, but it does not require as costly a monitoring program. When there is no discharge, there is no effluent to be tested.

A special type of intermittent discharge is seasonal discharge. This type of discharge is often used to protect high-quality streams, especially during the season when the stream is used a great deal for recreation. More storage is needed for seasonal discharge because there are usually only two discharges, one in spring and one in autumn. The effluent is discharged under controlled conditions approved by the regulating agencies.

METHODS OF DISPOSING AND MONITORING SEWAGE EFFLUENTS

Several methods of disposing of sewage effluents are used today. All methods must conform to the NPDES permit requirements and must be closely monitored. This section discusses these methods as well as troubleshooting problems with sewage effluent quality.

Direct Discharge to Receiving Water

Most treatment plants discharge effluent right into the receiving water. The abilities of the receiving water to dilute and accept the effluent is shown in the NPDES permit limits. The NPDES permit also considers the use of the receiving water. The effluent may come from a final clarifier, a disinfection contact basin, a lagoon, a polishing pond, or a storage pond. However, it must pass through some type of outfall sewer to the point of discharge.

The outfall sewer may be an enclosed pipe or an open channel or some of both. It is used to transport the effluent from the final treatment or storage unit to the point of discharge. The outfall sewer may be built to include cascades or stairsteps, channels, mechanical aerators, or a filter bed of coarse rock. The purpose of these aerators is to increase the DO content of the effluent.

The NPDES permit requires that certain tests be made on the effluent on a regular schedule. Effluent testing may include, but is not limited to, flow measurement, temperature, BOD or COD, suspended solids, pH, DO, coliform count, and chlorine residual. Test results must be reported to the regulating agency. Along with the required tests, operators should check the receiving water, especially on small streams and lakes. Laboratory tests and visual checks may show that a problem exists in the receiving water and that something needs to be done. Plant operators cannot usually test large rivers, bays, lakes, and gulfs.

If an effluent containing a toxic substance is accidentally discharged to a receiving water that is used downstream as a drinking water supply, for recreation, or for livestock watering, operators must call the regulating agency and the downstream water users at once. Regulating agencies can then help curb the problem, and drinking water suppliers will have enough time to close their water intake lines until the problem is stopped. This will also warn people in recreation areas and give farmers and ranchers time to move livestock to a safe water supply.

Discharge for Recycling

In some areas where there is a shortage of water, wastewater effluent is recycled for industry, recreation, irrigation, and fire control use. Many industries can use treated wastewater for cooling and cleaning. Often this is cheaper for the industry than using potable (drinking) water. Lakes for fishing and boating have been maintained with recycled wastewater. Records show that these man-made lakes are often no more hazardous to the users than natural lakes. Recycled wastewater is seldom used as a drinking water supply.

Monitoring of effluent discharged for recycling is very important. Only by monitoring can the operator be sure that the effluent is good enough to be used. Recycling units may include extended settling and biological stabilization in holding ponds, sand filtering, and disinfection. Quality control is a must since the recycled water must be safe.

Discharge for Land Application (Irrigation)

Irrigation with wastewater effluent is frequently used in some areas. Before irrigating, it is necessary to consider the contour of the area

for irrigation, soil type, ground water table, and potential damage to water supplies. The joint EPA/Army manual, EPA 625/1-77-008 *Process Design Manual for Land Treatment of Municipal Wastewater*, provides further guidance on this subject.

Hillsides and other areas with steep slopes are not often used for irrigation. Too much runoff may occur. Irrigation equipment is harder to move, control, and maintain. Each area to be used for irrigation should be surveyed by a qualified person. Often, areas with slopes on which normal farm machinery can be used can be irrigated by a sprinkler system or by a jet or spray gun. Terracing and contour furrowing help prevent runoff. Flooding, overland flow, and furrow irrigation may require special work done to the land. This may include leveling, grading, ditches, and dikes.

Soil type and structure affect the rate at which the wastewater can be applied and absorbed. Average loams and sandy loams absorb and filter well. Clay and other types of tight soil are not as good. Deep plowing and chiseling make these soils better for wastewater irrigation. Very sandy or gravelly soils have very high percolation or absorbing qualities. But when these soils are in contact with the ground water table, pollutants may get into underground water supplies before they can be filtered out. Tight, sandy, and gravelly soils can be improved for absorbing and filtering by plowing crops under.

Row crops may be watered by furrow, spray, and/or sprinkler irrigation. Spray irrigation is used where gravity flow is not practical in all parts of an effluent disposal plot or field. There should be gravity flow from one end of the row to the other. A lot of grading is needed to prepare a field for furrow irrigation. Long rows without enough slope will result in boggy parts of the field while other parts will not get enough water. Furrow irrigation on steep slopes may cause too much erosion. Operators in charge of this type of irrigation need special skill and experience to make sure a fairly even amount of water reaches all parts of the field.

Grass crops are often easy to irrigate. The grasslands may be pastures, meadows, parks, turf, or sodded areas of airfields and golf courses. The amount of water applied and how often it is applied are not as important as for row crops. Effluent can be applied to grassland by overland flow, sprinkler heads, or by jet or spray guns. The stems, leaves, and roots of the grasses make a good filter and help prevent rapid runoff. Grasses

and some other plants purify and release to the air large amounts of moisture when they are growing. During times of sunny, hot, and dry weather with strong breezes, as much as 25 percent of the water applied to the land may evaporate, either straight from the plants or from the surface of the soil.

Wooded areas and some wastelands have been used for effluent disposal. In these areas the disposal of the treated wastewater is most often the only reason for applying the effluent since crops are not grown there. These areas may absorb and filter the wastewater very well. The amount of wastewater applied to these lands is not as important as it is with crop irrigation.

The use of wastewater irrigation for vegetable and fruit crops that can be eaten uncooked may be restricted to protect public health. The health department or local regulating agency should be contacted before wastewater irrigation is applied to fruit and vegetable crops.

Wastewater effluent is often held in storage ponds or basins before it is used for irrigation. All discharge permit requirements must be met before the effluent can be used. Wastewater used on parks, golf courses, and other recreation areas should be disinfected just before it is applied. A chlorine contact chamber installed just upstream of the irrigation should be enough, but disinfection must meet the rules of the regulating agencies.

Testing of surface and subsurface water supplies in the immediate area of irrigation is important and must not be forgotten. Samples should be taken from all surface waters exposed to drainage and seepage of the irrigation water. Ground water should be tested using samples from existing wells or from test wells dug for that purpose. In areas where the water table is only a few feet below ground level, tests should be run very often. It is not as hard or as costly to prevent pollution as it is to clean up polluted water. Qualified laboratory technicians should check the soil to see if it is being hurt by buildups of toxics or by too many plant nutrients. Grazing and/or harvesting crops may help control soil conditions.

There must be enough storage capacity to hold the wastewater effluent until it is time to irrigate. The weather, type of soil, and type of crop are important in finding out how much to apply and how often to apply it. The wastewater should be disinfected before it is used for recreation. A power unit and a pump must be used unless gravity flow can be used to transport and distribute the effluent. A lightweight pipe like an

aluminum alloy or plastic is often used to carry the wastewater. Quick-coupling joints are needed so the pipe can be put together and taken apart easily. Sections of flexible hose are needed for mobile spray equipment and can also be used for bends in pipelines carrying the effluent. Valves are needed to control the amount of flow. Pressure release or bypass devices are needed to control pressure. Spray or sprinkler nozzles, heads, and guns must be able to adapt to the volume of water to be applied. They must also be designed to work in the range of water pressure maintained.

Evaporation and Percolation Basins

Evaporation and percolation basins are used to dispose of wastewater effluent by letting it evaporate and by letting it percolate or seep into the soil. The correct use of these ponds depends on the area of the basin compared to the amount and kind of the wastewater effluent to be processed. The larger the surface and bottom of the pond, the faster the wastewater evaporates and percolates. The climate and kind of soil are important in finding out whether this type of disposal can be used in a given area. This kind of system can be a good and cheap way to dispose of wastewater effluent.

It is often better to build two basins or one basin with a dike that separates it into two parts. After a time, suspended solids will change to settleable solids and build up in the pores or openings of the soil. Percolation will slow down and sooner or later will stop. To get the basin back in working order, it must be drained, dried, and cleaned. Scars must be cut in the bottom. With two basins, one can be kept in service while the other is being restored. The bottoms of the ponds should be sloped for quick and complete draining.

The berms or dikes must be checked often for erosion and rodent damage. The dikes and surrounding areas should be mowed often to keep vegetation at a maximum height of 6 to 10 inches (15 to 25 centimeters). This will help keep rodents out of the area. The area should be fenced to keep out larger animals.

Signs should be built to show that the ponds are wastewater treatment plants and are dangerous. As with wastewater lagoons, trees should not be allowed to grow within about 500 feet (150 meters) of the pond. There must be enough surface drainage around the edge of the pond to keep surface water from entering the unit.

Since there is no discharge from the system, there is no need for testing the pond effluent. All bodies of surface water and all wells in the area should be tested often to see if they have been polluted by the pond. Too many suspended solids discharged to the pond will stop up the unit. A suspended solids test must be performed daily (or at least very often) to find out if the treatment plant units are working well or if operative controls need to be changed. The ponds should be checked each day. Any changes in the way the plant looks or smells or any changes from normal operation need to be checked out. Laboratory tests may help find the problem and suggest ways of correcting it.

Troubleshooting

Table 10-13 describes some problems and solutions for these problems with wastewater effluent. Refer to manufacturers' manuals for more specific troubleshooting and operating guides for various types of treatment plants. Effluent quality

usually depends on the operation and maintenance of upstream process units.

Odors and unsightly conditions are the most common subjects of complaints. Toxic wastes and wastes with high fecal coliform count are more dangerous but are more difficult to detect. Therefore, fewer complaints are made regarding these two hazards.

Complaints must be received with courtesy and investigated at once to see if the complaint is valid. Be sure to inform the complaining person(s) as to your findings, what can be done or what is being done to remedy the problem. A careful investigation may show that the source of the problem is not related to the wastewater treatment plant.

If the treatment plant is the source of the problem, use all available operating controls to obtain maximum plant efficiency. Notify designated regulatory officials at once as to the nature of the problem. If the solution to the problem appears to be beyond operator control, request advice and/or assistance.

Table 10-13.—Troubleshooting Effluent Disposal

INDICATOR	LIKELY CAUSES	ACTIONS TO TAKE
Effluent BOD or COD too high.	<ol style="list-style-type: none"> 1. Organic overload. 2. Septic conditions in plant units and the collection system. 3. Not enough aeration. 	<ol style="list-style-type: none"> 1. Control organic loading by sewer use regulations. Improve plant upkeep. Use all available operating control. 2. Check sludge pumping schedule for proper removal. Inspect pumps to see if they are working. Inspect sludge pipes and valves for clogging, check for sludge deposits (pockets) that are not being pumped out of the clarifiers. Inspect all plant units whether primary or secondary for proper operation. Refer to manufacturer's instructions for process information. Inspect the collection system, including lift stations, for septic conditions. 3. Maintain the recommended DO level in all aerated units usually about 2 mg/l. Inspect air diffusers for even distribution of air and good mixing.
Effluent settleable solids content too high.	<ol style="list-style-type: none"> 1. Hydraulic overload. 2. Sludge collection and removal equipment not working right. 	<p>Try to control hydraulic loading by maintaining the collection system. Install holding ponds or tanks to handle peak load. Check on wastewater flow rate often to see if plant capacity is exceeded. Inspect settling tanks for short circuiting (channeling).</p>

Table 10-13.—Troubleshooting Effluent Disposal—Continued

INDICATOR	LIKELY CAUSES	ACTIONS TO TAKE
Effluent suspended solids content too high.	<ol style="list-style-type: none"> 1. Secondary units organically overloaded. 2. Hydraulic overload. 	<ol style="list-style-type: none"> 1. Keep organic loading of secondary units within design capacity if reasonably possible. Carefully inspect aerated units for DO content and mixing. 2. Same action as for too many settleable solids in the effluent due to hydraulic overload.
Effluent pH too low or too high.	<ol style="list-style-type: none"> 1. Industrial discharges not properly pretreated. 2. Septic conditions in collection system or in the treatment plant. 	<ol style="list-style-type: none"> 1. Inspect and sample the wastewater from the collection system to find the source. Require or provide proper pretreatment. 2. Inspect both collection system and plant for detention time in sewer pipes, wetwell, and clarifiers. Clean and flush clogged or partly clogged sewers. Aerate and/or chlorinate the influent wastewater for temporary relief.
Wastewater organisms killed, very little treatment being provided.	Toxic material leaking or being discharged to the collection system.	Immediately notify downstream users and regulatory authorities, giving all available information as to type and quantity of toxic substance, also time of release. If the operator has advance warning of a spill or discharge of toxic waste, then all available storage should be used to contain the toxic material instead of letting it pass through the plant. If it cannot be contained, use all available methods to neutralize and/or dilute the toxic waste. Try to find the source of the toxic material and use every reasonable means to prevent its discharge to the system.
Coliform count above permit requirement.	<ol style="list-style-type: none"> 1. Not enough chlorine being applied. 2. Chlorine not well mixed with the wastewater. 3. Contact time too short. 	<ol style="list-style-type: none"> 1. Test several times daily for "free" chlorine residual, especially during and immediately after peak flows. Adjust dose of chlorine according to test results. Inspect chlorine feed pump for working condition. If chlorine compounds such as HTH and others are being used, be sure of its percentage of chlorine content when adjusting the feed rate (dose). 2. Inspect mixing equipment to be sure the chlorine and wastewater are well mixed immediately. Test for free chlorine residual in several areas of the contact tank to be sure of proper mixing. 3. Carefully check the contact (detention) time of the tank to be sure that 15 to 30 minutes' contact time is provided. Remove sludge deposits, if any are present, from the contact tank.

SEPTIC TANKS, CESSPOOLS, AND LEACHING FIELDS

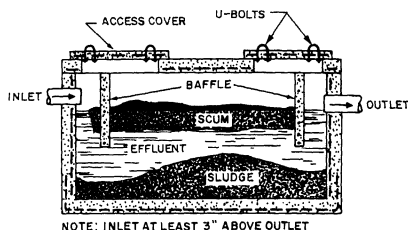
Septic tanks, cesspools, and leaching fields are used for sewage treatment processes where common sewers are not available. These facilities are for the most part underground receptacles. If they are properly designed, constructed, located, and operated, they work without objectionable odors over long periods of time with a minimum amount of attention.

SEPTIC TANKS

Septic tanks may be used to serve small or scattered installations where the effluent can be disposed of by dilution, leaching wells or trenches, subsurface tile, or artificial subsurface filter systems. See figure 10-2.

The septic tank capacity should equal a full day's flow plus an allowance of from 15 to 25 percent for sludge capacity. The minimum desirable size of the tank is 1,000 gallons. Table 10-14 outlines the minimum tank capacities required by the *National Standard Plumbing Code*.

Septic tanks are constructed of reinforced concrete. The length of the tank should be not less than two nor more than three times the width. The liquid depth should not be less than 4 feet for the smaller tanks and 6 feet for the larger ones. Manholes should be provided over the inlet and outlet pipes and over the low points in the



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Figure 10-2.—Septic tank.

Table 10-14.—Capacity of Septic Tanks

Single family dwellings—number of bedrooms	Multiple dwelling units or apartments—one bedroom each	Other uses; maximum fixture units served	Minimum septic tank capacity in gallons
1-3		20	1,000
4	2 units	25	1,200
5 or 6	3	33	1,500
7 or 8	4	45	2,000
	5	55	2,250
	6	60	2,500
	7	70	2,750
	8	80	3,000
	9	90	3,250
	10	100	3,500

Extra bedroom, 150 gallons each.
 Extra dwelling units over 10, 250 gallons each.
 Extra fixture units over 100, 25 gallons per fixture unit.

NOTE: Septic tanks sizes in this table include sludge storage capacity and the connection of domestic food waste disposal units without further volume increase.

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bottom of hopper-bottom tanks. The roof of the tank may be covered with earth, but access openings should extend at least to the ground surface. Although ells or tees may be used at inlet and outlet connections, straight connections are better for rodding. Instead of ells, wooden baffles, located approximately 18 inches from the ends of the tank and extending 18 inches below and 12 inches above the flow line, are provided. Elevations should permit free flow into and out of the tank. The bottom of the inlet sewer should be at least 3 inches above the water level in the tank. The inlet and outlet connections should be sufficiently buried or otherwise protected to prevent damage by traffic or frost.

When a tank will discharge into a leaching field greater than 500 feet in length, a dosing tank and siphon should be incorporated into the system (fig. 10-3). The rush of sewage that occurs when the siphon discharges results in better distribution throughout the leaching field. While the dosing tank is refilling, the resultant resting period is favorable to maintaining aerobic conditions in the receiving soil. The dosing tank should have a capacity about 60 to 75 percent of the interior capacity of the leaching pipe to be dosed at one time and should automatically dose once in 3 to 4 hours. Double the amount of dosing siphons

for each additional 500 feet of leaching tile or pipe.

Although properly designed septic tanks require little operating attention, they must be inspected periodically. The frequency is determined by the size of the tank and the population load. The minimum frequency should be once every 2 months at periods of high flow. The inspection should assure that the inlet and outlet are free from clogging, that the depth of scum and sludge accumulation is not excessive, and that the effluent passing to subsurface disposal is relatively free from suspended solids. A high concentration of suspended solids in the effluent quickly clogs subsurface disposal facilities. Sludge and scum accumulation should not exceed one-fourth the tank capacity. It should not be assumed that septic tanks liquefy all solids, that they never need cleaning, and that the effluent is pure and free from germs. Perhaps 40 to 60 percent of the suspended solids are retained and the rest are discharged in the effluent.

Separating sludge and scum from the liquid in septic tanks is difficult. In small tanks these wastes are customarily mixed, and the entire contents are removed when the tanks are cleaned. The

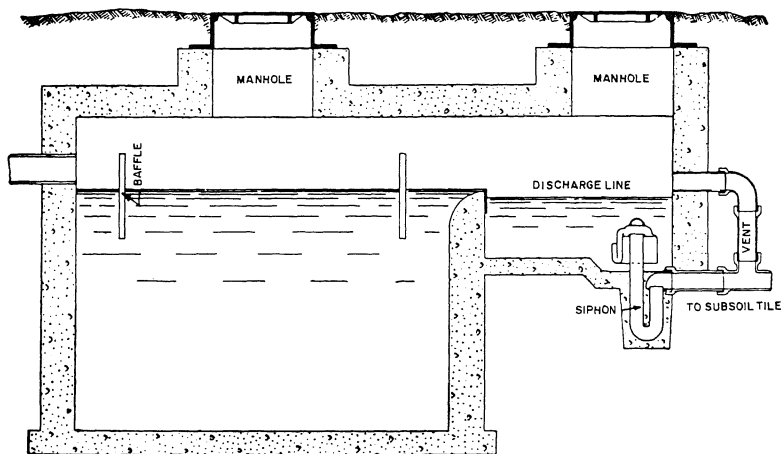


Figure 10-3.—Septic tank with dosing siphon.

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material removed contains fresh or partially digested sewage solids. It must be disposed of without endangering public health. Disposal through manholes in the nearest sewerage system, as approved by local authorities, or burial in shallow furrows on open land is recommended. A diaphragm-type sludge pump is best suited for removing the tank contents. The contents should be transported in a watertight, closed container.

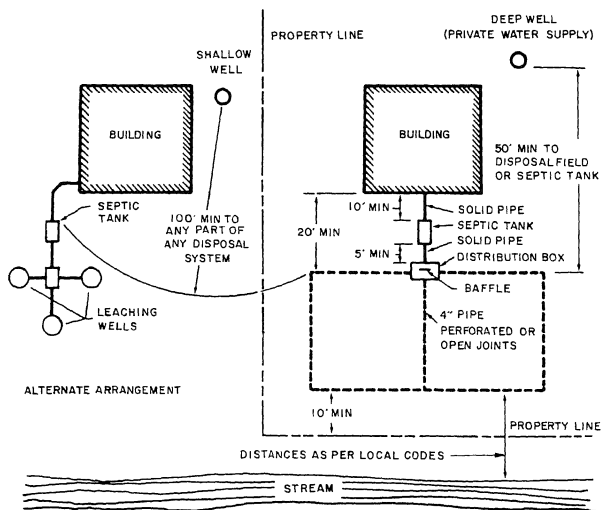
When installing a septic tank system for sewage treatment, you must take into consideration the location with respect to wells or other sources of water supply, topography, water table, soil characteristics, area available, and the maximum building occupancy. Building occupancy is a key factor in determining tank size. Table 10-15 shows the common sewage uses based on the type of facility and the gallons per person per day of usage.

The physical location of a septic tank in relation to wells must be no closer than 100

feet to a shallow well and no closer than 50 feet from a deep well. In general, a shallow well is classified as a well less than 100 feet in depth. Deep wells are generally more than 100 feet in depth. Figure 10-4 shows a typical septic tank system layout with minimum distances noted. Keep in mind that septic tanks, cesspools, and leaching fields must be located downhill from any water source.

CESSPOOLS

Sewage from private dwellings and farmhouses in outlying areas may discharge into cesspools if a common sewerage system is not available. Cesspools are usually dry-laid masonry or brick-lined wells without any masonry at the bottom. The sewage flows into them and leaches out into the soil. Floating solids collect at the top and settling solids collect at the bottom of the well. The well's leaching capacity is exhausted when the solids accumulate and clog the soil. The use of chemicals is not recommended



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Figure 10-4.—Minimum distances for location of components of a private sewage disposal system.

Table 10-15.—Sewage Flows According to Type of Establishment

Type of Establishment	Gal per Day per Person
Schools (toilet and lavatories only)	15 gal per day per person
Schools (with above plus cafeteria)	25 gal per day per person
Schools (with above plus cafeteria and showers)	35 gal per day per person
Day workers at schools and offices	15 gal per day per person
Day camps	25 gal per day per person
Trailer parks or tourist camps (with built-in bath)	50 gal per day per person
Trailer parks or tourist camps (with central bathhouse)	35 gal per day per person
Work or construction camps	50 gal per day per person
Public picnic parks (toilet wastes only)	5 gal per day per person
Public picnic parks (bathhouse, showers and flush toilets)	10 gal per day per person
Swimming pools and beaches	10 gal per day per person
Country clubs	25 gal per locker
Luxury residences and estates	150 gal per day per person
Rooming house	40 gal per day per person
Boarding houses	50 gal per day per person
Hotels (with connecting baths)	50 gal per day per person
Hotels (with private baths—two persons per room)	100 gal per day per person
Boarding schools	100 gal per day per person
Factories (gallons per person per shift—exclusive of industrial wastes)	25 gal per day per person
Nursing homes	75 gal per day per person
General hospitals	150 gal per day per person
Public institutions (other than hospitals)	100 gal per day per person
Restaurants (toilet and kitchen wastes per unit of serving capacity)	25 gal per day per person
Kitchen wastes from hotels, camps, boarding houses, etc. Serving three meals per day	10 gal per day per person
Motels	50 gal per bed space
Motels with bath, toilet, and kitchen wastes	60 gal per bed space
Drive-in theaters	5 gal per car space
Stores	400 gal per toilet room
Service stations	10 gal per vehicle served
Airports	3-5 gal per passenger
Assembly halls	2 gal per seat
Bowling alleys	75 gal per lane
Churches (small)	3-5 gal per sanctuary seat
Churches (large with kitchens)	5-7 gal per sanctuary seat
Dance halls	2 gal per day per person
Laundries (coin operated)	400 gal per machine
Service stations	1,000 gal (First bay) 500 gal (Each add. bay)
Subdivisions or individual homes	75 gal per day per person
Marinas—Flush toilets	36 gal per fixture per hr
Urinals	10 gal per fixture per hr
Wash basins	15 gal per fixture per hr
Showers	150 gal per fixture per hr

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to increase the useful life of a cesspool. See figure 10-5.

When the first cesspool becomes filled, a second well may be built to take the overflow from the first. In such cases, the first cesspool should operate as a septic tank to collect the settling and floating solids and provide a trapped outlet on the connection leading to the next leaching cesspool. Septic tanks may be placed advantageously ahead of leaching cesspools in larger installations. Leaching cesspools should not be placed closer together than 20 feet by out-to-out measurement of walls.

Leaching cesspools should be used only where the subsoil is porous to a depth of at least 8 or 10 feet and where the ground water is normally below this elevation. When they are located in fine sand, the leaching area can be increased by surrounding the walls with graded gravel.

The number and the size of cesspools required depend on the quantity of sewage and the leaching characteristics of the total exterior percolating area above the ground water table, including bottoms and sidewalls below the maximum-flow lines. The allowable rate of sewage application per square foot per day, based on the recommended leaching test, is given below. Soils that require more than 30 minutes for a fall of 1 inch are

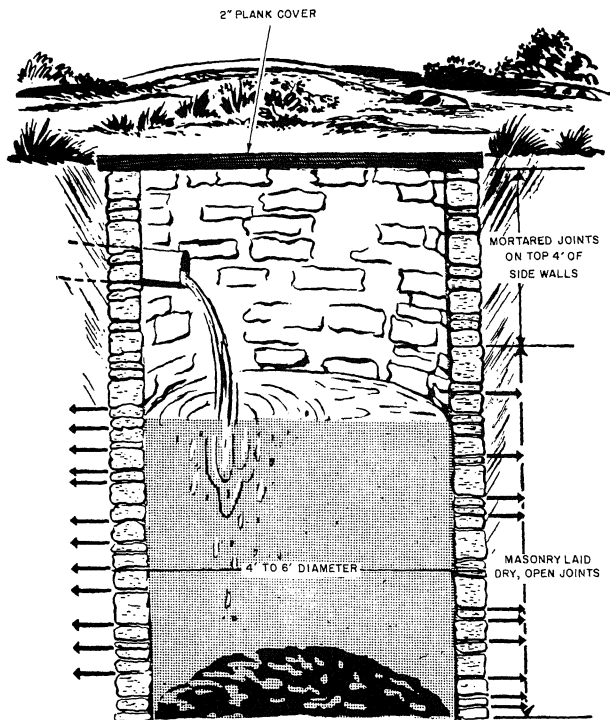


Figure 10-5.—Leaching cesspool.

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unsatisfactory for leaching. Some other disposal method should be used.

<u>Time for water to fall 1 inch (minutes)</u>	<u>Allowable rate of sewage application (gallons per square foot of percolating area per day)</u>
1	5.3
2	4.3
5	3.2
10	2.3
30	1.1

The test for leaching should be made by digging a pit about one-half the proposed depth of the cesspool, making a test hole 1 foot square and 18 inches deep at the bottom. The test hole is filled with 6 inches of water, which is allowed to drain off. Six inches of water is again added, and the downward rate of percolation is measured in minutes required for the water surface to lower 1 inch in the hole.

LEACHING FIELDS

Leaching fields are an integral component of a septic tank individual sewage disposal system. Leaching fields may be referred to as tile fields or absorption trenches. Whichever term is used the function, testing, construction, and maintenance techniques of this component remain the same.

Leaching fields are built of lines of 4-inch perforated pipe. Asbestos cement, vitrified clay pipe, or fiber perforated pipe (Orangeburg alkacid) are commonly used. Many types of perforated pipes are commercially available for use in leaching field construction. The newer plastic pipe is becoming more popular and is the most desirable because of its light weight, ease of installation, and varying lengths.

The following conditions are important for the proper functioning of a leaching field:

- Ground water levels well below that of the leaching field
- Soil of satisfactory leaching characteristics within a few feet of the surface extending several feet below the leaching pipe
- Subsurface drainage away from the field

- Adequate area

- Freedom from polluting drinking water supplies, particularly from shallow wells in the vicinity

Before installing a leaching field in a specified area a percolation test must be performed. This test will determine whether the area selected is suitable for subsurface sewage disposal and helps you to determine the overall size of the leaching field in relation to trench dimensions and pipe lengths.

The test consists of digging a test pit 2 feet square and at least 1 foot in depth. The optimum depth should be at the deepest point that the leaching pipe will be laid. Next dig a hole 1 foot square by 1 foot deep in the test pit. Fill this hole with 7 inches of water for wetting purposes. Allow the water to drop to 6 inches before recording the drop time. Then note the time required for the level to drop 1 inch (from 6 to 5 inches) in depth. You can then determine the length of pipe in the leaching field by using table 10-16. Note that this table is based on the assumption that 4-inch pipe will be used as recommended by the *National Standard Plumbing Code*.

In the construction of a leaching field, the installer takes into consideration the results of the percolation test, type of soil, size of pipe, depth in reference to the ground water level and frost line, and standard requirements of materials

Table 10-16.—The Tile Length for Each 100 Gallons of Sewage Per Day

Time in Minutes for 1-inch Drop	Tile Length for Trench Widths of		
	1 foot	2 feet	3 feet
1	25	13	9
2	30	15	10
3	35	18	12
5	42	21	14
10	59	30	20
15	74	37	25
20	91	46	31
25	105	53	35
30	125	63	42

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placed in the absorption trench. Figure 10-6 shows a typical layout of a leaching field.

Soil type at the location of the field will dictate the width of the trench. Sand and sandy loam require a width of 1 foot, loam and sand and clay mixture 2 feet, clay with some gravel 3 feet. Note these are minimum trench widths based on the soil type encountered at the jobsite.

Placing the leaching pipe below the frost line to prevent freezing is not necessary. The depth should not under any circumstances be deeper than the ground water level.

When digging the absorption trenches, you must consider the lengths of each lateral and their

spacing in relation to each other. Do not make any lateral longer than 100 feet in length. Table 10-17 shows the size and spacing requirements for disposal fields.

After the trenches are laid out and dug, filler material is placed along with the actual pipe. The filler material may be washed gravel, crushed stone, slag, or clean bank-run gravel ranging in size from 1/2 to 2 1/2 inches in size. Filler material placed into the trench should not be less than 6 inches deep below the bottom of the pipe. It should be at least 2 inches above the pipe. To prevent backfill soil from filling the voids in the filler material, it is recommended that a 3-inch

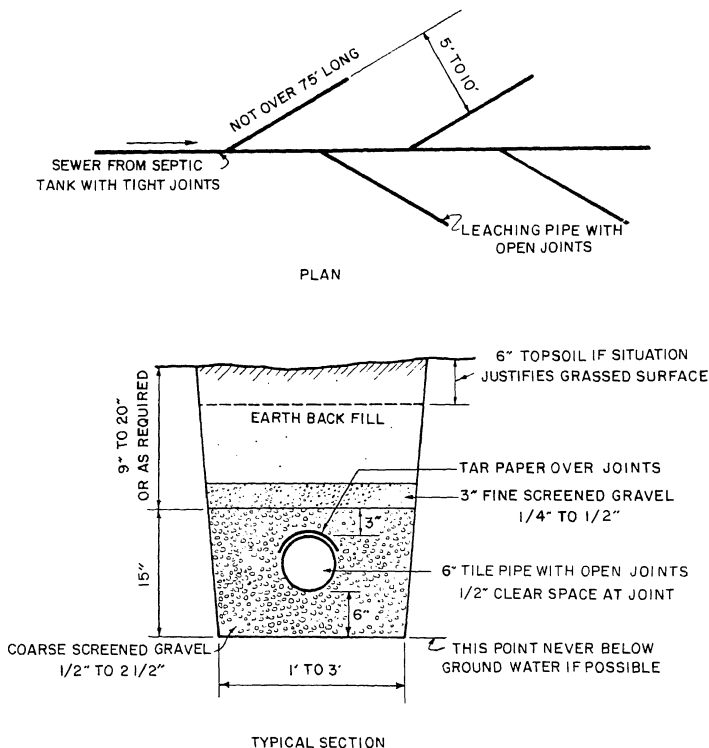


Figure 10-6.—Typical layout of a subsurface tile system.

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Table 10-17.—Size and Spacing for Disposal Fields

Width of trench at bottom (in.)	Recommended depth of trench (in.)	Spacing tile lines* (ft)	Effective absorption area per lineal ft of trench (sq ft)
18	18 to 30	6.0	1.5
24	18 to 30	6.0	2.0
30	18 to 36	7.6	2.5
36	24 to 36	9.0	3.0

*A greater spacing is desirable where available area permits.

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layer of medium-screened gravel with another layer of fine-screened gravel, untreated paper, or straw of 2 to 3 inches in depth be placed in the trench.

Pipe is laid with a minimum pitch of 2 inches to a maximum of 4 inches per 100 feet. When open joints are used, they must not be spaced more than one-half inch apart. Asphalt-treated paper is used to cover the joint. The open joint allows for free discharge of solids from the line to the trench. The asphalt-treated paper prevents gravel from entering the pipe.

The layout of the field requires attention to detail to prevent future maintenance and operation troubles. When the field is laid on sloping ground, the flow must be distributed so each lateral gets a fair portion of the flow. Individual lines should be laid nearly parallel to land contours. Leaching fields are commonly laid out either in a herringbone pattern (fig. 10-6) or with the laterals at right angles to the main distribution pipe.

Little or no maintenance is required for leaching fields. Preventive measures such as excluding all vehicle traffic and not planting trees or shrubs in the field area will ensure troublefree operation for extended periods of time, usually many years.

When a leaching field becomes unoperational, you must replace it with a new system. Tree or shrub roots are a major factor in leaching field failure and require the replacement of the field components and complete root removal.

REFERENCES

- Intermediate Sewage*, NTTC Course 216, NAVFAC P-335, NAVFAC Technical Training Center, Norfolk, Va., May 1969.
- National Standard Plumbing Code, Illustrated*, National Association of Plumbing-Heating-Cooling Contractors, Washington, D.C., 1984.

CHAPTER 11

COMPRESSED AIR SYSTEMS

Learning Objective: Recognize the installation and maintenance considerations of compressed air systems.

The Utilitiesman will be involved in the installation of compressed air systems as part of projects. The senior UT must be capable of identifying and directing the proper construction techniques and installation of fittings and components. You will also be involved in the maintenance of previously installed systems. This chapter is aimed at increasing your knowledge of these considerations.

SYSTEM CLASSIFICATIONS

Compressed air is a form of power that has many important uses in industrial activities. An air compressor plant (fig. 11-1) is required to supply air of adequate volume, quality, and pressure at the various points of application, stated as pounds per square inch gauge (psig). These plants or systems are classified as

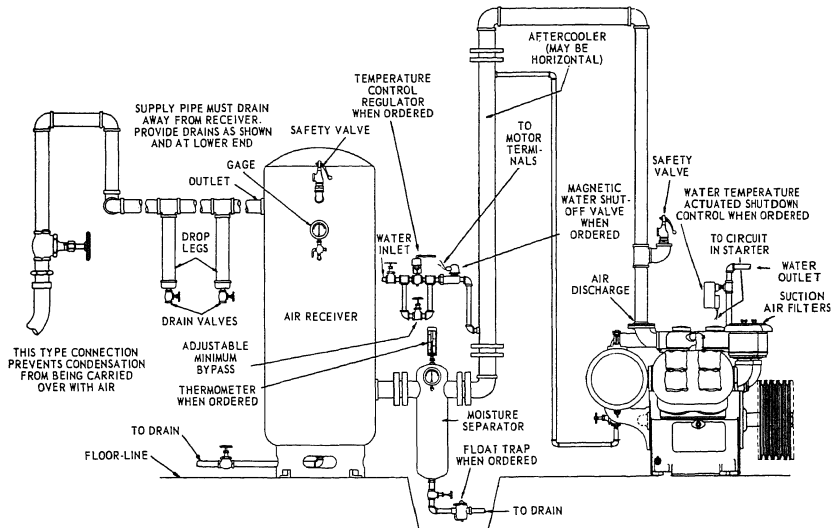


Figure 11-1.—Components of a compressed air plant.

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low-pressure (0 to 125 psig), medium-pressure (126 to 399 psig), or high-pressure (400 to 6,000 psig) systems.

LOW-PRESSURE SYSTEMS

Low-pressure systems provide compressed air up to 125 psig pressure. When you are installing a low-pressure system, pressure is usually reduced at reducing stations for branches requiring lower pressures. Several air pressure requirements for low-pressure air consumers are listed below:

Laboratories	5 to 50 psig
Shops	60 to 125 psig
Laundries and dry cleaning plants	70 to 100 psig
Hospitals	20 to 50 psig
Ordinary service (tools, painting, and so forth)	60 to 80 psig
Soot blowing for boilers	80 to 125 psig

MEDIUM-PRESSURE SYSTEMS

Medium-pressure systems provide compressed air within the range of 126 to 399 psig pressure. These systems are not extensive and are generally provided with individual compressors located near the loads. Medium-pressure systems are mainly used for the starting of diesel engines, soot blowing of boilers and high-temperature water (HTW) generators, and hydraulic lifts.

HIGH-PRESSURE SYSTEMS

These systems provide compressed air within the range of 400 to 6,000 psig pressure. Hazards that increase with higher pressures and capacities can be minimized by the use of separate compressors for each required pressure. Systems operating at 3,000 psig may require small amounts of air at lower pressures, which is supplied through pressure-reducing stations.

Caution must be used with high-pressure systems because when high-pressure air enters suddenly into pockets or dead ends, the air temperature in the confined space increases dramatically. If there is any combustible material in the space and the air temperature increases to the ignition point of the material, an explosion may occur. This is known as auto ignition or diesel action. Explosions of this type may set up shock waves that travel through the compressed air system. This travel may cause explosions at

remote points. Even a small amount of oil residue or a small cotton thread may be sufficient to cause ignition.

Some common pressure requirements for high-pressure systems may be as follows:

Torpedo workshop	600 to 3,000 psig
Ammunition depot	100, 750, 1,500, 2,000, and 4,500 psig
Wind tunnels	Over 3,000 psig
Testing laboratories	Up to 6,000 psig

AIR QUALITY REQUIREMENTS

The quality of air supplied from a compressed air system will vary with application. The installer and maintenance personnel should consider the class of air entrapment and specific air quality requirements for each application.

CLASSES OF AIR ENTRAPMENT

The classes of air entrapment may be subdivided into inert and chemical particulates, chemical gases, oil, and water. To prevent contamination of an air compression system by these types of entrapments, you should follow certain guidelines for each situation of possible contamination.

Particulates

Intake structures or openings should be free of shelves, pockets, or other surfaces that attract and accumulate particulates. Properly designed intakes are large enough to produce a low-velocity airflow. This limits the size of the particles that may be picked up by the intake suction.

Some particulates may contain active chemicals that may form acids or alkalines in the inevitable presence of water. These chemical particulates can accelerate damage to compressor surfaces.

Particulates are sized in microns or micrometers. This measurement is size, not weight. One micron is a unit of length equal to one millionth of a meter. Particles larger than 10 microns are visual to the naked eye. Filter systems are required for all air compressors. Generally, filters should be able to remove particles down to 1 to 3 microns in size.

Gases or Fumes

Gases or fumes are fully airborne and generally independent of air velocity. They can

be strong acid, alkaline, or otherwise corrosive to the internal surfaces or lubricants of the compressor. In addition, gases or fumes may be prohibited by the end-use process, such as medical gases or breathing air and for environmental or odor reasons. Intakes near normal flow paths of engine exhausts should be avoided.

Oil

Oil fumes, vapor, or mist can be as difficult to handle as particulates or gases. Even though many types of compressors are oil lubricated, the oil ingested may not be compatible and compressor load may be increased.

Water

Waste and water vapor are always present in air intakes. Installation of intakes should prevent the accumulation of free water. Free water ingested into the compressor causes damage to internal components.

Since water vapor with chemical content corrodes steel piping, precautions must be taken to protect materials from corrosion. Galvanizing, applying protective coatings, or using plastic or stainless steel piping for air intakes are some suggested methods to retard or prevent corrosion. Also be sure to install intakes in a manner that excludes rainfall, snow, or spray by applying a weather hood.

SPECIFIC AIR QUALITY REQUIREMENTS

The diverse uses of air are accompanied by specific air quality requirements. These vary from high purity requirements through the need to introduce materials into a system to be carried along with the air. This section will discuss these specific air quality requirements.

Commercial Air

Commercial compressed air is graded according to its purity. The purest is grade A running alphabetically to grade J, the least pure. The Compressed Gas Association has set guidelines for the grading of commercial compressed gas. The application of commercial compressed air is varied and generally specified for each individual installation by engineers. The full extent of the quality requirements for commercial compressed air applications can be located in the Compressed Air Association publication *Commodity Specification for Air*, G-7.1 (ANSI 286.1-1973).

Breathing Air

Breathing air must be of high quality for obvious reasons. Federal Specification BB-A-1034 (fig. 11-2) outlines the specific requirements for breathing air.

Component	Source I (Pressurized Container Air)		Source II (Compressed Air)	
	Grade A	Grade B	Grade C	Grade D
Oxygen (by volume) percent	20 to 22	19 to 23	20 to 22	19 to 23
Carbon dioxide (by volume)	500 parts per million (ppm) max	1,000 ppm max	500 ppm max	1,000 ppm max
Carbon monoxide (by volume)	10 ppm max	10 ppm max	10 ppm max	10 ppm max
Oil (mist and vapor) and particulate matter (weight/volume)	0.005 milligrams (mg) per liter, max	0.005 mg per liter, max	0.005 mg per liter, max	0.005 mg per liter, max
Separated water	None	None	None	None
Total water (weight/volume)	0.02 mg per liter, max	0.3 mg per liter, max (Dew point—20 degrees F.)	0.02 mg per liter, max	0.3 mg per liter, max (Dew point—20 degrees F.)

Figure 11-2.—Breathing air requirements, Federal Specification BB-A-1034A AM1.

Special attention must be given to eliminating carbon monoxide (CO), carbon dioxide (CO₂), hydrocarbons, odor, and water from breathing air. Carbon monoxide has first priority as its effects are cumulative and very small concentrations can cause problems. Whenever possible, carbon monoxide monitoring should be provided at the compressor intake. This monitoring equipment should sound an alarm or shut down the system when CO is detected.

Carbon dioxide is found in combustion flue gases such as boiler stacks. Do not place compressor intakes near or downwind of the stacks.

Systems should be kept free of oil to limit the possible concentration of hydrocarbons or petroleum products. For breathing air, compressors should be oil free rather than using auxiliary petroleum removal equipment. The heat caused by compression may cause thermal breakdown of oil or an explosion danger may exist as a result of drawing hydrocarbons into the air system.

Water content is kept below saturation to prevent condensation at points that cannot be cleaned. It is recommended that refrigerant or dessicant dryers be used to remove moisture from a breathing air system. This will limit the vapor clouding (fogging) of glasses and visors.

Medical Air

Medical air quality must be the same or better than breathing air. Whatever quality is established must be strictly adhered to.

Instrument and Control Air

Air quality requirements for instrument and control air should place emphasis on cleanliness and low moisture content. The Instrument Society of America (ISA) has established the following requirements:

- Dew point, exterior: 18°F (−7.8°C) below minimum recorded ambient temperature
- Dew point, interior: 18°F (−7.8°C) below minimum interior temperature but not higher than 35°F (1.7°C)
- Particle size: 3 microns maximum
- Oil content: As close to zero as possible but not over 1 ppm

- Contaminates: No corrosives or hazardous gases

Water content must be low enough to prevent condensate accumulations. Special attention should be given to ensure that intake air is filtered and oil or water removed. A refrigerant dryer with a dew point at least as low as 30°F (−1.1°C) is recommended for these services.

Aircraft Starting and Cooling Air

Aircraft starting air requires reasonably clean air to prevent introduction of excessive levels of oil, water, or particulates into engine systems. Normal intake filtering and oil/water separation should be adequate.

Aircraft cooling air is intended for electrical load cooling to prevent malfunction of the equipment. Cooling air should be reasonably clean. This air may also be used for breathing. If it is, then breathing air quality standards should be maintained.

Air for Pneumatic Tools

When compressed air is intended for use with pneumatic tools, it should be filtered for particulates and water should be separated out. Oil is usually required to be ingested into the air for tool lubrication. Mist injection is preferred for tools to ensure dispersion and maximum settlement. Note that pressures in excess of 400 psig may cause compression combustion when oil is present.

High-Pressure Air Systems

Air quality must be carefully analyzed to minimize not only the normal hazards of high pressure, but the internal explosive hazards that exist with high-pressure systems. Of particular danger is the introduction of oil and hydrocarbons during compression and their remaining and accumulating throughout the system. A high-pressure system of 500 psig or higher is subject to rapid local heat buildup whenever there is a rapid filling of a component or vessel. The heat buildup (combined with oil and foreign material) that permits the oil to wick or vaporize can readily cause an explosion or fire. Any explosion in the system may produce several shock waves to travel the system, compounding the damage. Because of this problem, special attention is required to clean the intake air, limit the introduction of

lubrication oil, and remove oil after completion of the compression process.

AIR COMPRESSORS AND AUXILIARY EQUIPMENT

There are basically two types of compressors: positive displacement and dynamic. This section will discuss the reciprocating air compressors, the rotary air compressors, the helical screw compressors classed as positive displacement compressors, and the dynamic centrifugal compressors.

General auxiliary equipment will also be discussed. Auxiliary equipment consists of any device(s) that may be added to the system to improve its efficiency or provide a specific function. It provides a safe condition under which the compressor system will be operating.

RECIPROCATING AIR COMPRESSORS

The most commonly used stationary air compressors are the reciprocating, positive displacement design. They may be single acting or double acting, single stage or multistage, and horizontal, angle, or vertical in design.

In a single-stage unit there is but one compressing element; it compresses air from the initial intake pressure to the final discharge pressure in one step. A multistage machine has more than one compressing element. The first stage compresses air to an intermediate pressure, then one or more additional stages compress it to the final discharge pressure.

In the reciprocating compressor the compression cycle is composed of three phases: intake, compression, and discharge.

During the intake stroke the downward movement of the piston creates a partial vacuum inside the cylinder. The spring-operated intake valve is forced open by the differential pressure between free air on one side and the partial vacuum inside the cylinder. As the valve opens, air fills the cylinder. The piston now moves into the compression stroke, forcing the intake valve closed and raising the pressure of the air trapped in the cylinder. When the pressure of this air is great enough to overcome the force of the

spring-operated discharge valve, the valve opens and the compressed air is discharged from the cylinder.

Compressors are classified as low pressure, medium pressure, or high pressure. Low-pressure compressors provide a discharge pressure of 150 psi or less. Medium-pressure compressors provide a discharge pressure of 151 psi to 1,000 psi. Compressors that provide a discharge pressure above 1,000 psi are classified as high pressure. Note that compressors are classified at different pressures than those for classifying total compressed air systems discussed earlier.

Most low-pressure air compressors are of the two-stage type with either a vertical or a vertical W arrangement of cylinders. Two-stage, V-type, low-pressure compressors usually have one cylinder that provides the first (low-pressure) stage of compression and one cylinder that provides the second (high-pressure) stage, as shown in figure 11-3. W-type compressors have two cylinders for the first stage of compression and one cylinder for the second stage. This arrangement is illustrated in figure 11-4.

Compressors may be classified according to a number of other design features or operating characteristics.

Medium-pressure air compressors are of the two-stage, vertical, duplex, single-acting type. Many medium-pressure compressors have differential pistons, as shown in figure 11-5. This type of piston provides more than one stage of compression on each piston.

ROTARY AIR COMPRESSORS

Rotary sliding vane compressors are machines in which longitudinal vanes slide radially in a slotted rotor that is mounted eccentrically in a cylinder. The rotor is fitted with blades or vanes that are free to slide in and out of longitudinal slots and maintain contact with the cylinder walls by centrifugal force. In operation, as the blades are forced outward by centrifugal force, compartments are formed in which air is compressed (fig. 11-6). Each compartment varies from a maximum volume on the suction side of the revolution to a minimum volume on the compression half of the revolution. This gives a positive displacement-type suction and pressure effect.

Another type of rotary compressor is the twin-lobe unit sometimes referred to as a blower

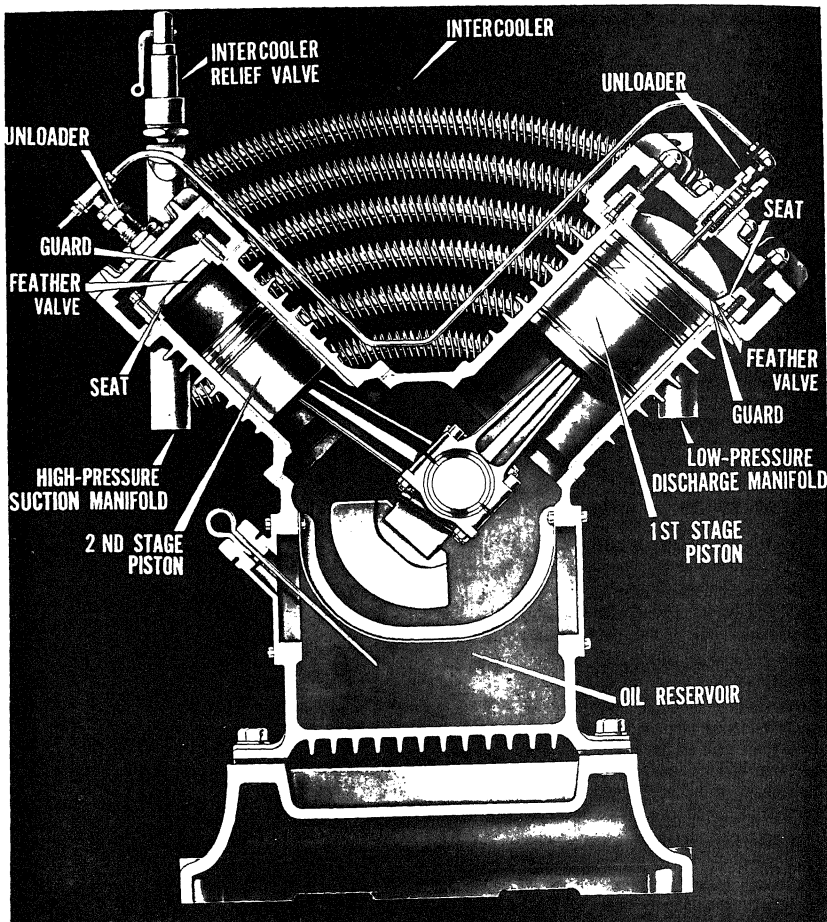
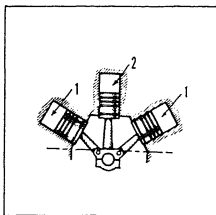


Figure 11-3.—A typical two-stage reciprocating low-pressure air compressor.

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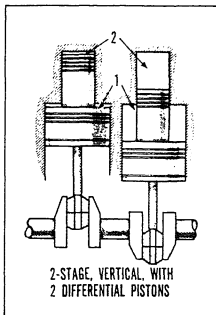
(fig. 11-7). This unit consists of two impellers mounted on parallel shafts that rotate in opposite directions within a housing. As the impellers rotate, they trap a quantity of air between themselves and the blower housing and move the air around the casing to the discharge port. This

action takes place twice each revolution of an impeller and four times per revolution of both impellers. The impellers are positioned in relation to each other by timing gears, located at the end of each shaft and external to the blower housing.



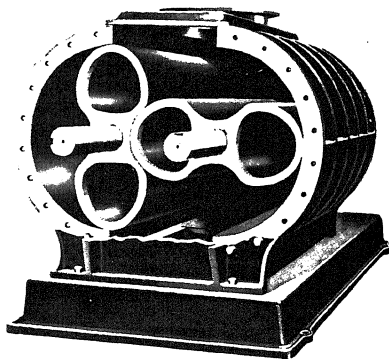
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Figure 11-4.—W-type, two-stage, three-cylinder arrangement.



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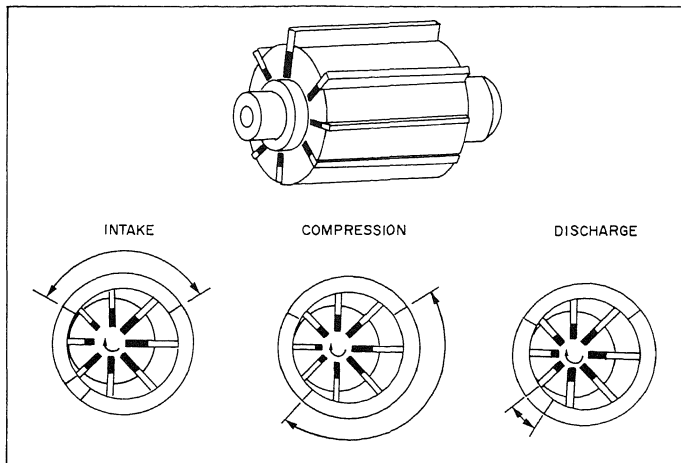
Figure 11-5.—Differential piston with a two-stage, vertical arrangement.



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Figure 11-7.—Twin-lobe rotary compressor.

You should always use maintenance and service literature provided by manufacturers when you are working with rotary compressors. Maintenance information is given in *Operation and Maintenance of Compressed Air Plants*, NAVFAC MO-206.



87.250

Figure 11-6.—Compression cycle of rotary compressor.

HELICAL SCREW COMPRESSORS

Helical screw compressors contain two mating rotating screws, one locked and one grooved, which provide the driving force. The unit's screws take in air, decreasing its volume as it progresses in a forward-moving cavity toward the discharge end of the compressor. Figure 11-8 shows a typical single-stage compressor and a double-stage helical screw compressor. These compressors are best used in booster or near constant-load conditions at low-pressure, oil-free application. Helical screw compressors may also be found in aircraft start facilities.

DYNAMIC CENTRIFUGAL COMPRESSORS

Dynamic compressors are high-speed rotating machines in which air is compressed by the

action of rotating impellers or blades that impart velocity and pressure to the air. Figure 11-9 shows the internal parts of a multistage centrifugal compressor. This type will deliver air at an essentially constant pressure over a wide range of capacities. The direction of airflow is radial with respect to the axis of rotation.

Centrifugal compressors have a lower limit of stable operation called the surge point. Operation below this point results in pumping or surging of the airflow. Prime movers are normally electric motors or steam turbines.

Centrifugal compressors are intended for near continuous industrial air service when the load is reasonably constant. These compressors also work well when oil-free air is required and can be used for breathing air.

Table 11-1 shows typical application recommendations for both positive displacement and dynamic class compressors.

AUXILIARY EQUIPMENT

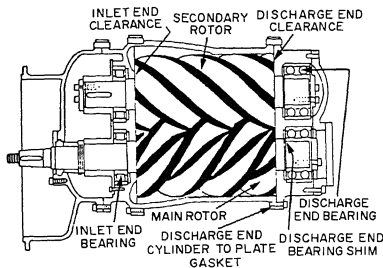
A system that functions to provide a continuous supply of usable compressed air requires certain auxiliary devices in addition to the air compressor. Most compressed air systems require a minimum of auxiliary equipment that should include air intakes, intake filters, silencers, intercoolers, aftercoolers, air discharge systems, separators, dryers, receivers, and so forth. These auxiliary equipments will be discussed in this section in addition to less common auxiliary equipment.

Air Intakes

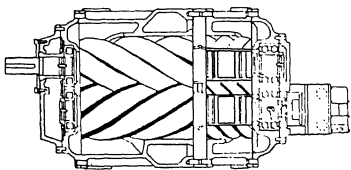
Air intakes should be located high enough to eliminate intake of particles of dust, smoke, dirt, water, and snow. Carbon monoxide sources should not be able to discharge into compressor intakes. Special attention should be given to the elimination of flammable fumes into the compressed air system.

Whenever air intakes must be placed through a roof that is surrounded by parapets, they should be 8 to 10 feet above the roof.

Noise may be generated by air intakes and must be considered during installation. Reciprocating compressors are most likely to develop resonance through intake piping. If this possibility exists, the use of intake dampeners or surge chambers will help. High velocities present noise level problems. Intake pipe velocities should be limited to 1,000 fpm in open areas or 350 fpm across filters. Acoustical silencers combined with filters and/or pulse dampeners are available and



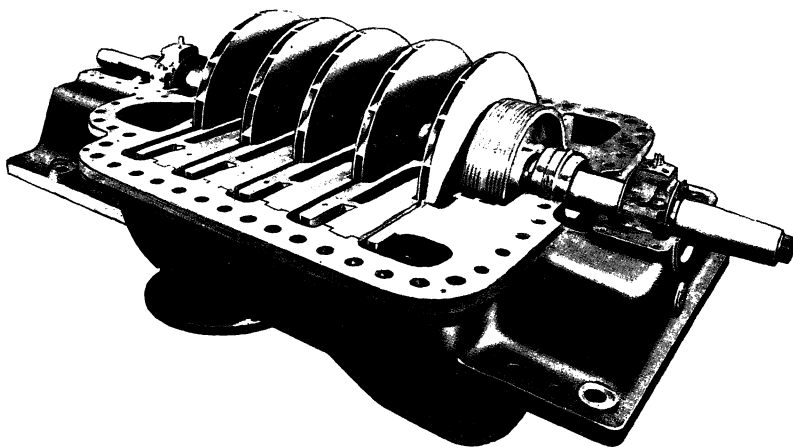
TYPICAL SINGLE-STAGE DESIGN



TYPICAL TWO-STAGE DESIGN

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Figure 11-8.—Rotary helical screw compressors.



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Figure 11-9.—Internal view of a multistage centrifugal compressor.

Table 11-1.—Summary Application Recommendations, Types of Compressors

Type	Air* Delivery Quality	Pressure Range scfm Range Horsepower Range	Remarks
Reciprocating, single-stage, air cooled	L	100-125 psig, to 50 scfm, to 10 hp	Intermittent light duty
Reciprocating, two-stage, air cooled	L	100-125 psig, to 200 scfm, to 50 hp	Low volume requirements
Reciprocating, two-stage, air cooled	N	100-125 psig, to 50 scfm, to 15 hp	Low volume requirements
Reciprocating, two-stage, water cooled	L	100-150 psig, 400-1,000 scfm, 75-200 hp	Wide application range
Reciprocating, two-stage, water cooled	N	100-125 psig, 400-1,000 scfm, 75-200 hp	Wide application where required
Reciprocating, two-stage, water cooled, duplex and/or double acting	L	100-150 psig, 1,000-5,000 scfm, 200-1,200 hp	High volume requirements

(1 psig = 6.90 kPa gauge, 1 scfm = 0.0268 mm³/min, 1 hp = 0.746 kW)
 *L—Lubricated
 N—Nonlubricated

Table 11-1.—Summary Application Recommendations, Types of Compressors—Continued

Type	Air* Delivery Quality	Pressure Range scfm Range Horsepower Range	Remarks
Reciprocating, multi-stage, water cooled	L, N	150-6,000 psig, 10-100 scfm, 3-1,000 hp	Medium and high pressure
Rotary, sliding vane, single-stage	L, N	5-50 psig, 50-3,000 scfm, 0.5-300 hp	Match to load only pressure booster
Rotary, sliding vane, two-stage	L, N	60-100 psig, 100-3,000 scfm, 15-500 hp	Match to load only pressure booster
Rotary, sliding vane, single- or two-stage oil injected	L	80-125 psig, 120-600 scfm, 15-200 hp	Wide application range
Helical screw, single-stage, lubricated	L	To 35 psig, 30-12,000 scfm, to 1,200 hp	Match to load only single rating point
Helical screw, two stage lubricated	L	60-100 psig, 30-12,000 scfm, to 2,000 hp	Match load only. Single rating point. Aircraft air start. Aircraft cooling
Helical screw, single-stage, oil injected	L	To 125 psig, 40-1,500 scfm, 10-400 hp	Wide application range
Dynamic, centrifugal, single-stage	N	To 35 psig, 1,500-15,000 scfm, 100-1,000 hp	Match load
Dynamic, centrifugal, two-stage	N	35-70 psig, 1,500-15,000 scfm 100-2,000 hp	Match load, breathing air
Dynamic, centrifugal, three-stage	N	70-125 psig, 1,500-15,000 scfm, 200-3,500 hp	High volume requirements, breathing air
Dynamic, centrifugal, four or more stages	N	125 psig or more, 1,500-15,000 scfm, to 3,000 hp	Medium pressure high volume
Dynamic, axial or radial barrel, multi-stage	N	200 psig or more, 1,500 scfm or more, high horsepower	Medium and high pressure, high volume

(1 psig = 6.90 kPa gauge, 1 scfm = 0.0268 mm³/min, 1 hp = 0.746 kW)

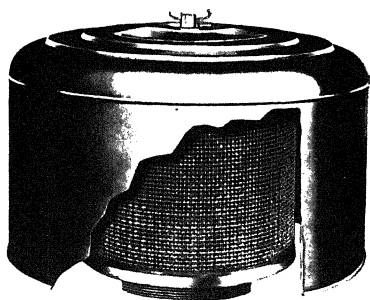
*L—Lubricated
N—Nonlubricated

should be used whenever potential noise level difficulties are anticipated.

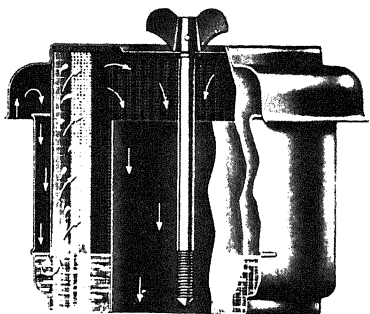
Intake resistance to airflow should be no more than necessary to maintain air quality. The resistance created by the air intake system will reduce compressor performance and efficiency. Refer to the compressor manufacturer's manual for maximum resistance requirements.

Intake Filters

Air filters are provided on compressor intakes to prevent atmospheric dust from entering the cylinders and causing scoring and excessive wear. The two most common types of elements in use are the VISCOUS IMPINGEMENT and the OIL BATH. Both types are illustrated in figure 11-10.



VISCOUS IMPINGEMENT TYPE



OIL BATH TYPE

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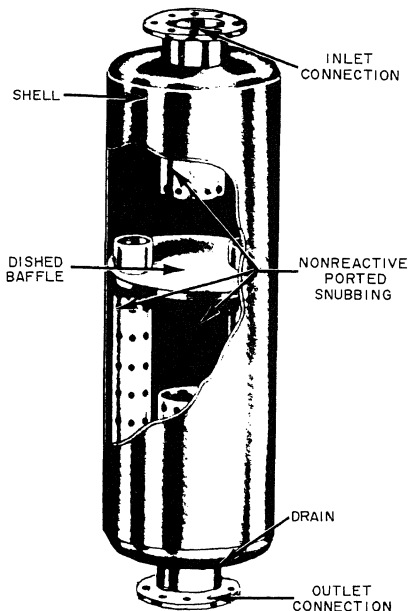
Figure 11-10.—Compressor intake filters.

In the oil bath type, air must pass through an oil seal that removes dirt particles, and then pass on through a wire mesh element, which is saturated by oil carry-over. Any remaining particles of dirt are removed by the wire mesh element. Captured dust particles settle to a sump at the bottom of the filter housing. Oil bath filters are recommended where dust concentrations are present in the atmosphere.

The viscous impingement filter consists of a wire mesh filter element, which is coated with oil. Air passing through the filter element must change directions many times, causing any dust to adhere to the oil film.

Silencers

Silencers are similar to mufflers and function simply to eliminate objectionable compressor suction noise. Figure 11-11 illustrates a standard



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Figure 11-11.—Intake silencer.

intake silencer. Some compressors are equipped with combination filter-silencer units that have the filter elements contained within the silencer housing.

Intercoolers

When air is compressed to 100 psi without heat loss, the final temperature is about 485 °F. The increase in temperature raises the pressure of the air under compression, thus necessitating an increase in work to compress the air. After the air is discharged into the receiver tank and lines, the temperature falls rapidly to near that of the surrounding atmosphere, thereby losing part of the energy generated during compression. The ideal compressor would compress the air at a constant temperature, but this is not possible. In multistage compressors, the work of compressing is divided between two or more stages, depending on the final discharge pressure required. An INTERCOOLER is used between the stages to reduce the temperature of compression from each stage. Theoretically, the intercooler should be of sufficient capacity to reduce the temperature

between stages to that of the low-pressure cylinder intake. Actually, intercooling has three purposes: to increase compressor efficiency, to prevent excessive temperatures within the compressor cylinders, and to condense out moisture from the air.

Most intercoolers are either the shell and tube, air-to-water heat exchangers or the air-cooled radiator-type heat exchangers. Figure 11-12 illustrates a typical water-cooled intercooler. The air-cooled type is shown in figure 11-3.

Aftercoolers

Moisture carried in air transmission lines is undesirable because it causes damage to air-operated tools and devices. AFTERCOOLERS are installed in compressor discharge lines to lower the air discharge temperature, thus condensing the moisture and allowing it to be removed. Also, the cooling effect allows the use of smaller discharge piping. A water-cooled aftercooler is illustrated in figure 11-13.

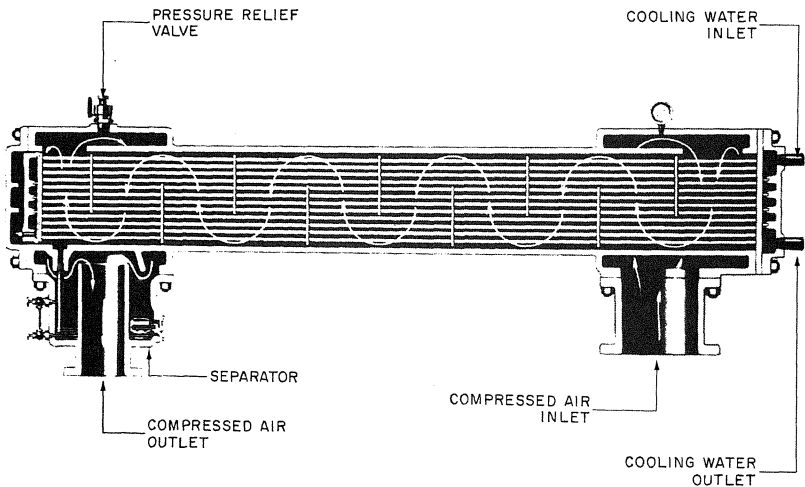
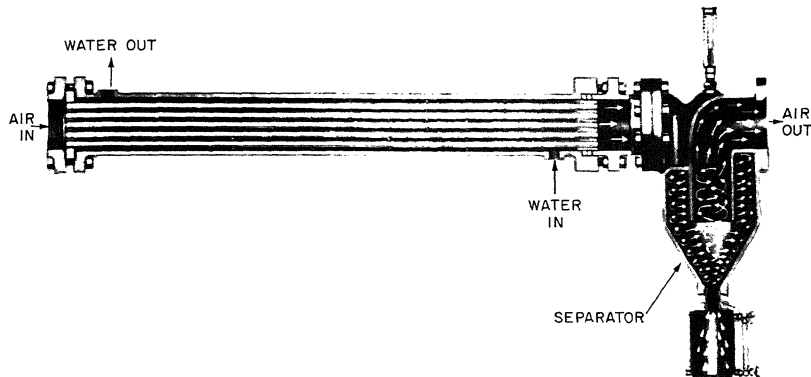


Figure 11-12.—Typical water-cooled intercooler.

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Figure 11-13.—Typical water-cooled aftercooler.

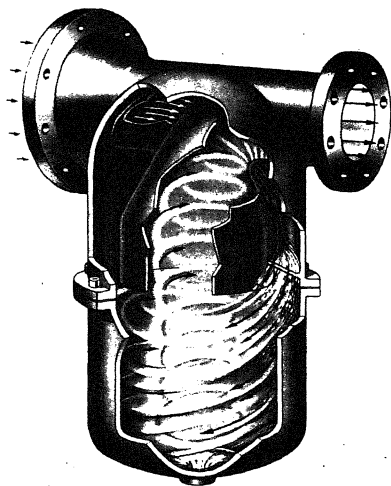
Air Discharge Systems

Some discharge systems require special consideration for the placement of auxiliary equipment. All positive displacement compressors require a relief valve on their discharge side to protect the equipment and piping upstream of the first shutoff valve. Relief valves should be sized for at least 125 percent of the maximum unit flow capacity and should carry the American Society of Mechanical Engineers (ASME) stamp, listing the capacity and pressure setting of the valve.

Separators

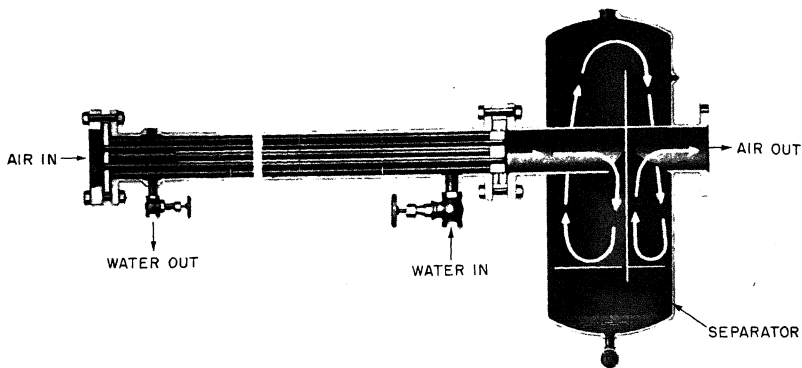
Water and oil separators are required to separate and free excess water from the discharge air or gas. This is necessary to prevent corrosion, deposit buildup, and water or oil buildup in the piping or service. For example, water will cause rust in piping, wash away lubricants, and plug nozzles. Oil will contaminate many industrial processes and may present an explosion hazard. The need for water or oil separators will be determined by the end use of the compressed air.

A centrifugal separator is illustrated in figure 11-14. Air is directed into this unit in a manner that creates a swirling motion. Centrifugal force throws the moisture particles against the wall where they drain to the bottom.



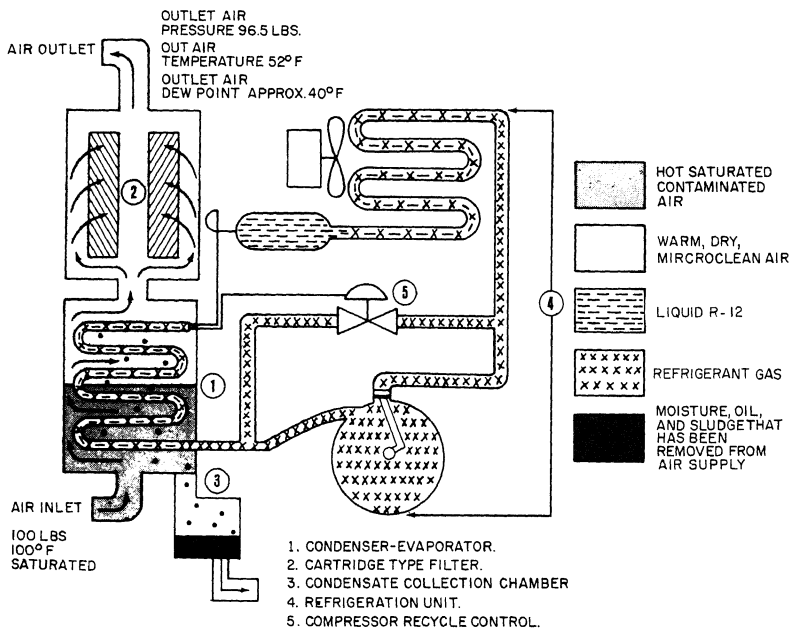
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Figure 11-14.—Centrifugal-type moisture separator.



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Figure 11-15.—Baffle-type moisture separator.



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Figure 11-16.—Flow process of refrigeration-type air dryer.

A baffle-type separator is illustrated in figure 11-15. In this unit the air is subjected to a series of sudden changes in direction that result in the heavier moisture particles striking the baffles and walls, then draining to the bottom.

Dryers

Some compressed air supplies require dryers that ensure removal of all moisture that might otherwise condense in air lines, air-powered tools, or pneumatic instruments. Small amounts of moisture can cause damage to equipment from corrosion, freezing, and water hammer and can result in malfunctions of instruments and controls. The cost of dryers is often justified by the reduction in maintenance costs, production time lost in blowing down piping, and compressed air lost during blowdown.

There are three basic designs of dryers: two absorption types and a condensation type. One type of absorption unit consists of two towers, each containing an absorbent material. Reactivation is accomplished by means of electric or steam heaters embedded in the absorbent or by passing dried-process air through it.

Another type of absorption unit consists of a single tank or tower containing a desiccant (drying agent) that dissolves as it absorbs moisture from the air and drains from the unit with the condensate. The drying agent must be replenished periodically.

The third type removes moisture from the air by condensation through the use of a mechanical refrigeration unit, or where available, cold water. Inlet air passes over cold coils where moisture is condensed out of the air and is drained from the unit by a trap. This process is illustrated in figure 11-16.

Receivers

Air receiver tanks in compressed air plants act as surge tanks to smooth the flow of air from the action of the compressor to discharge; they collect excessive moisture that may condense from the cooled air and provide a volume of air necessary to operate the pressure control system. A typical air receiver is shown in figure 11-17. Related components include a relief valve, pressure gauge, drain valve, service valve, and inspection opening.

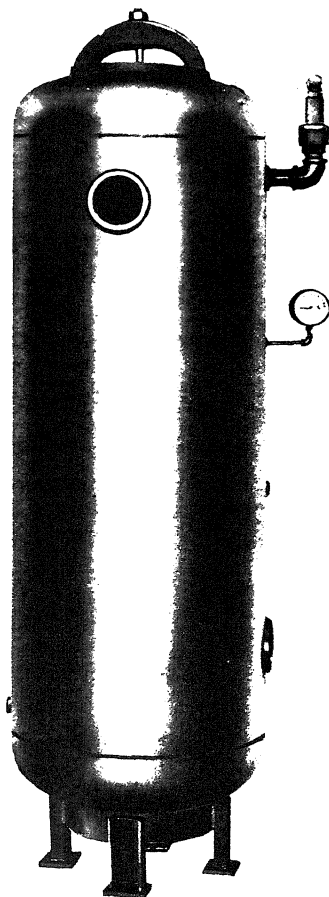


Figure 11-17.—Air receiver.

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Lubrication

Compressors must receive adequate lubrication using clean oil of characteristics recommended by the compressor manufacturer. The manufacturer will usually specify oil requirements

by characteristics, such as viscosity at one or more temperatures, pour point, flash point, and in some cases, by specific brands.

Typical compressor cylinder oils will have the following characteristics:

Flash point, °F	350	minimum
Viscosity at 210°F	45	min - 90 max
Pour point, °F	+35	maximum
Neutralization number	0.10	maximum
Conradson carbon residue, %	2.0	maximum

Where cylinder lubrication is separate from frame and bearing lubricants, a modified set of characteristics may be specified. Synthetic oils must conform to the manufacturer's requirements and must be used with care as many synthetic oils may cause swelling and softening of neoprenes

and certain rubbers or may not be compatible or separable from water.

Some special considerations for lubricants include the provision of a lubrication oil heater to ensure adequate viscosity during cold weather start-up. High compressor discharge temperatures require lubrication flows and characteristics that still lubricate when subjected to 300 °F or higher discharge air temperature conditions. Finally, oil injection or oil-flooded compressors need adequate oil flow and characteristics to maintain lubrication of temperatures within the cylinders or screws.

A typical lubrication arrangement is shown in figure 11-18.

Discharge Pulsation

Reciprocating compressor discharge lines are subject to pulsations caused by the compressor-forcing frequency. This sets up a resonant frequency in the discharge piping, and the resulting vibration amplification will cause noise, support damage, and piping damage. There

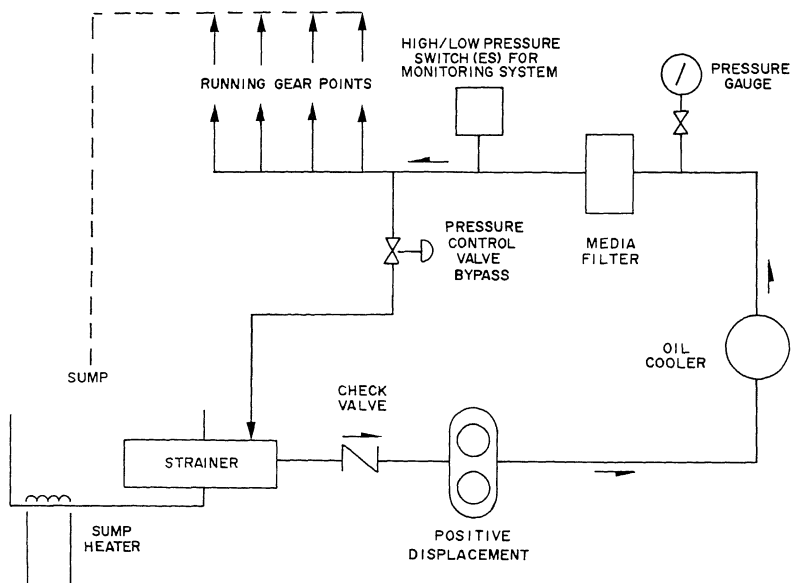


Figure 11-18.—Typical pressure lubrication system.

is no single solution to this problem, but some specific guidelines will be discussed below.

Pulsation dampeners serve as pulsation and noise mufflers by providing acoustical chambers with the dampener. Manufacturers generally provide dampeners to a specified discharge pulsation peak of ± 2 percent of line pressure. Figure 11-19 shows several typical pulsation dampeners. These units should be used whenever reciprocating and centrifugal compressors serve the same compressed air main, because the pulsations of the reciprocating compressor can transmit to and disturb the operation of the centrifugal compressor. Pulsation dampeners may not completely solve downstream resonance, but they will reduce the vibration amplitudes.

Several other ways to decrease noise and amplification caused by discharge pulsation are available. Surge chambers can be used to change the equivalent length of the piping and increase the pulse-absorbing volume of the pipe. A surge chamber can be as simple as an increased diameter of discharge piping near the compressor discharge. An orifice plate or plates may be installed in conjunction with surge chambers to change the acoustical resonant frequency of the piping system. Piping support is also important at the compressor. They must not only be supported from top or bottom but also have lateral support. When piping is large, provide spring-loaded two-way lateral supports to absorb vibration.

Controls

Compressor control systems generally include one or more controlling devices, such as safety controls, speed controls, and capacity controls. Such devices function in the system to regulate the output of the compressor as it meets the demand for compressed air.

On some small compressors the simple Bourdon tube-type pressure switch serves as a controller by actuating the prime mover on and off over a predetermined pressure range. More complex compressors require control systems that load and unload the compressor as air demands change. The CONSTANT-SPEED type of controller used with many compressors decreases or increases compressor capacity in one or more steps by the use of unloading devices, while allowing the prime mover speed to remain constant. Another type, referred to as the DUAL-CONTROL, is a combination of the constant-speed and an automatic start-stop control. It permits constant speeds when demands are continuous and an automatic stop or start when demands are light. There is still another system that enables the prime mover to idle and compressor suction valves to remain open when air pressure reaches a set maximum. As the pressure drops below a set minimum, the prime mover speed is increased, suction valves are closed, and air is compressed.

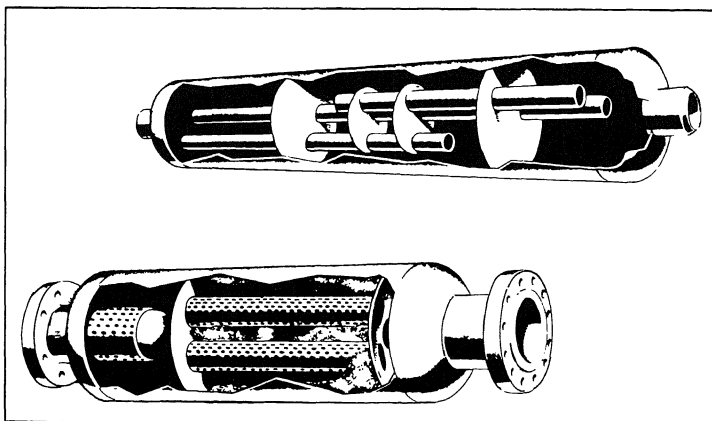


Figure 11-19.—Pulsation dampeners.

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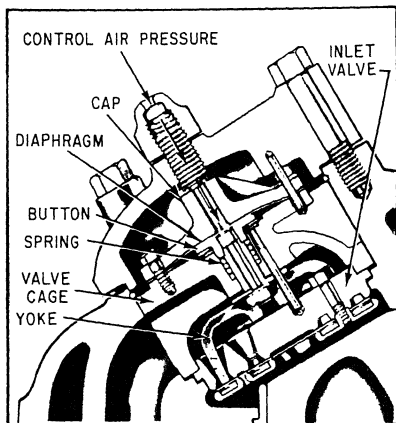


Figure 11-20.—Inlet valve unloader.

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Generally, control systems include unloading devices that function to remove all but the friction loads on compressors. Thus starting is unaffected by compression loads. Various types of unloading devices are discussed below.

The inlet-valve-type unloader holds the inlet valve open mechanically during both the suction and compression strokes, thereby preventing compression. Figure 11-20 illustrates a common inlet valve unloader. The unloader is positioned above the inlet valve. When air pressure rises to the preset unloading pressure, a pressure switch operates a solenoid unloader valve, which opens and allows receiver pressure to the inlet valve unloader. The pressure from the receiver, acting on the diaphragm of the inlet valve unloader, forces the yoke fingers against the inlet valve, holding it open. The intake air is pushed back out the inlet valve on the compression stroke so no compression takes place.

Figure 11-21 illustrates the thin plate, low-lift type of compressor valve. Most compressors use this type of valve.

The use of an unloader valve on each cylinder and a pressure switch with a solenoid unloader valve provides a step or sequenced capacity control. Figure 11-22 illustrates a flow diagram of a

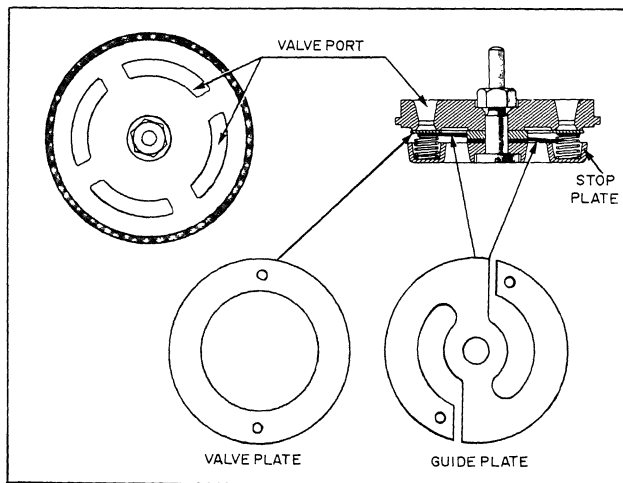


Figure 11-21.—Thin plate, low-lift, compressor valve assembly.

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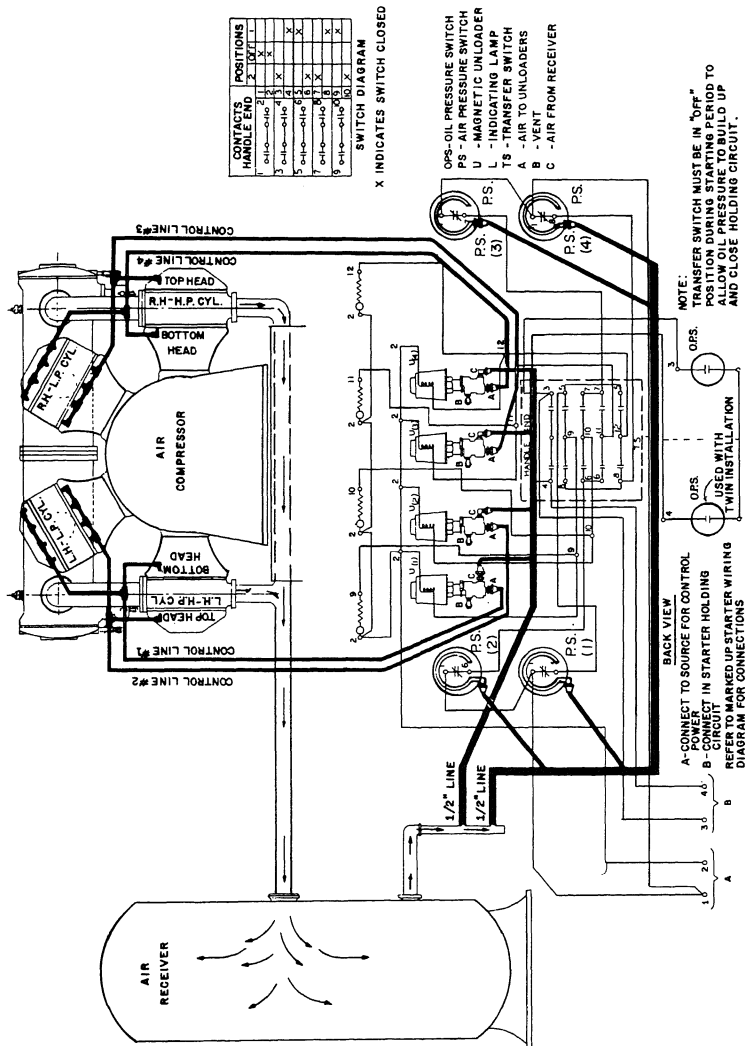


Figure 11-22.—Five-step capacity control.

five-step capacity control system applied to a two-stage, four-cylinder, double-acting, reciprocating compressor. Assuming that the compressor in the figure is required to maintain a pressure of 92 to 100 psi, the pressure switches should be set to load and unload as follows: switch 1, load at 93 psi and unload at 97 psi; switch 2, load at 94 psi and unload at 98 psi; switch 3, load at 95 psi and unload at 99 psi; and switch 4, load at 96 psi and unload at 100 psi. As the receiver pressure reaches the high limit of each pressure switch, 25 percent of the compressor capacity will unload. As receiver pressure falls to the low setting of each switch, 25 percent of the compressor capacity will load. Pressure switch 1 will therefore unload 25 percent of the compressor capacity at 97 psi and will load 25 percent at 93 psi, and so forth. As receiver pressure fluctuates between 93 and 100 psi, the compressor capacity varies in five steps; full, 75 percent, 50 percent, 25 percent, and zero capacity.

The compressor illustrated in figure 11-22 operates on the following principle: When it is started, air pressure switches are closed and the solenoids in the unloader valves become energized so that receiver pressure cannot enter the unloading lines, and compression is permitted. As the receiver pressure builds up and reaches 97 psi, pressure switch 1 breaks contact, de-energizing unloader 1, and allowing 97 psi receiver air to enter control line 1, actuating the inlet valve unloader. Twenty-five percent of the compressor has become unloaded and compression has reduced from full to 75-percent capacity. Control lines 2, 3, and 4 will operate in the same way as receiver pressure increases. At 100 psi, all cylinders will be unloaded. Air compression ceases, but the compressor continues to run under no load. As air is drawn off from the receiver, the pressure begins to drop. When the pressure falls to 96 psi, pressure switch 4 makes contact and energizes unloading valve 4, which cuts off receiver pressure from the inlet unloader and vents the unloader pressure to the atmosphere. The inlet valve unloader releases the inlet valve and normal compression takes place, loading the compressor to 25-percent capacity. If the demand for air increases and receiver pressure continues to decrease, control lines 3, 2, and 1 will load in sequence.

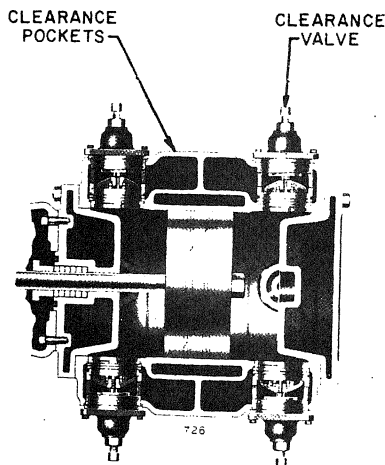
Another method of unloading a compressor is by the use of clearance pockets built into the cylinders. Normal clearance is the volume at the end of the piston and under the valves when the piston is at the end of the COMPRESSION

stroke. Figure 11-23 shows an air cylinder with clearance pockets and clearance valves used with a five-step clearance control. Each end of the cylinder is fitted with two clearance pockets that are connected with or cut off from the cylinder by air-operated clearance valves. A regulated device, not shown, which is operated by receiver pressure, uses pilot valves to open and close the clearance pocket valve in the proper sequence. Each clearance pocket can hold one-quarter of the air compressed by the cylinder in one stroke. When both pockets at the end of the cylinder are open, no air is taken into that end of the cylinder. Figure 11-24 illustrates the operation of clearance pockets under five-step clearance control.

Prime Movers

Prime movers for compressors can be electrical, gasoline, or diesel driven. This section will address electrical prime movers only. Gasoline and diesel-driven prime movers are normally the responsibility of the Construction Mechanic.

Several types of electric motors can be used to drive compressors: induction, synchronous-wound motor, and direct current (dc) motors.



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Figure 11-23.—Air cylinder showing clearance pockets and clearance valves.

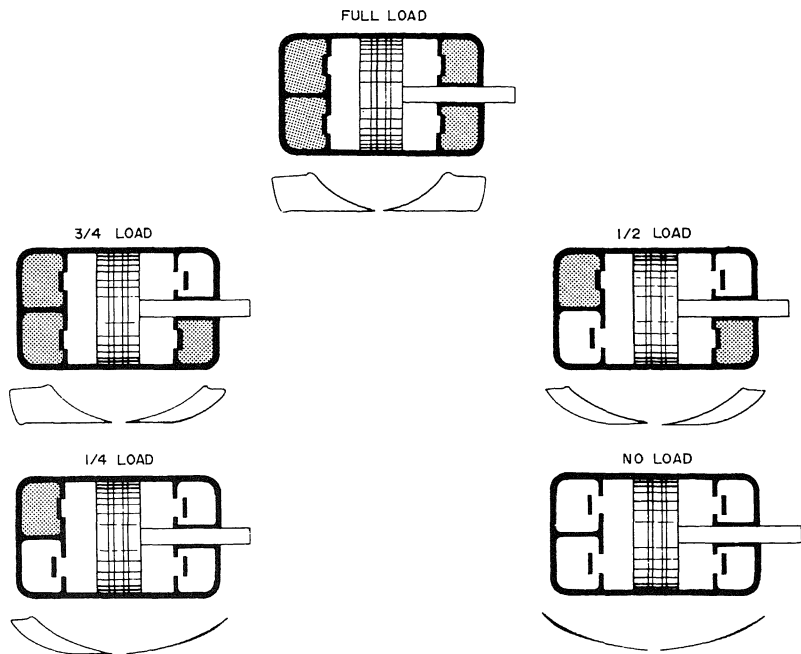


Figure 11-24.—Five-step clearance control.

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Although electric motor drive is available for compressors of almost any capacity, certain types of machines are best driven by an induction motor; others may be driven by a synchronous motor. Generally, cost will rule out synchronous motors except in unusual cases. Direct current motors are seldom used.

Motor-driven compressors may be further identified by the type of connection that is used between the motor and compressor. Any one of the following types of drives may be used: belt, direct-connected, or speed reduction gears.

Induction motors can be used to power single-acting reciprocating compressors ranging from fractional horsepower up to approximately 300 horsepower at a speed of 1,800 rpm. Speeds of 1,200 and 900 rpm and lower are sometimes

used in higher horsepower applications. When sizing a motor, you must allow for belt or drive losses of power.

Caution must be exercised when large belted motors are used; manufacturer's recommendations should be applied. Most motors that are belted to compressors are rated as normal starting torque, low-starting current motors. Belt selection should be based on a continuous operation rating of at least 125 percent of motor size with 150 percent preferred. Other compressors that start under load may require motors rated as high-start torque, low-starting current. Consideration should be given to compressor inertia and load to avoid lengthy acceleration time. Whenever possible, it is best

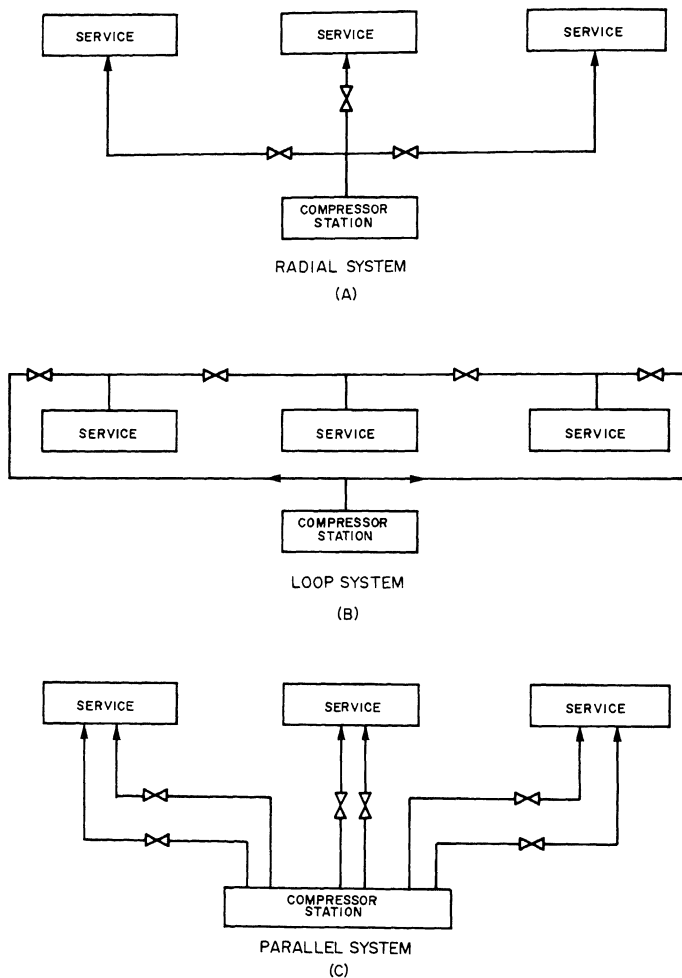


Figure 11-25.—Types of air distribution systems.

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to arrange the compressor to be unloaded during start-up.

A reciprocating compressor may be driven by an induction motor with a speed reduction gear placed between the motor and compressor. This permits the use of a higher speed with a less costly motor. Gear-driven compressors should have flywheel or inertia effect carefully checked. Couplings should have enough elasticity and dampening to allow for torque and current pulsations. Without this consideration, changes in torque caused by load variations or loading and unloading of a compressor could result in drive and motor damage.

DISTRIBUTION SYSTEMS

The development of a distribution system is dependent upon a combination of factors, such as location and size of each service, time rate demand of larger services, and concurrence or demand factor of larger services.

TYPES OF AIR DISTRIBUTION PIPING SYSTEMS

The more common types of distribution systems or patterns (fig. 11-25) and their prime advantages are as follows:

- Radial, one-way system—used for isolated or individual service or where special requirements dictate a single path.
- Loop system—used for a closed route such as throughout a building. The two-directional flow capacity represents an economical way to provide constant pressure to all services and permits selective isolation when necessary.
- Parallel system—used to provide dual service source to ensure at least one source will be available at all times.

SIZING DISTRIBUTION SYSTEMS

Compressed air distribution systems are sized mainly by calculating the friction loss to be expected from piping, fittings, and

valves as well as various accessories you may install.

Pipe diameters are determined from commercially available products, such as copper, stainless steel tubing, or steel piping. As contained pressure increases, the pipe wall thickness must increase and interior diameters decrease. This affects friction pressure loss; it should not exceed 15-percent pressure loss.

When you are determining total friction loss for a distribution system, the total length of the system piping plus the equivalent length of each fitting, valve, or device is summed to produce an equivalent hydraulic length. The equivalent lengths of fittings, valves, and other devices can be determined from table 11-2. Friction loss in air hoses may be taken from table 11-3.

LAYOUT DETAILS

When installing compressed air systems, you must follow seven basic guidelines just as you must consider basic guidelines when installing any other type of piping or drainage system.

Compressed air lines should be installed as level as practical with a slight pitch in the direction of airflow. This pitch is generally placed at 3 inches per 100 feet of piping. In cases when pipes must be pitched upward causing condensate to flow against the flow of air, the pitch upward must be 6 inches or greater per 100 feet, and the piping size should be increased one pipe diameter.

The layout of the piping systems should always allow for the removal of dirt, water, oil, or other foreign material, which can accumulate over long periods of time. Because of this, pockets should be avoided and, where necessary, low points should be provided with driplegs. In addition to providing low points to drain foreign material from the system, the prevention of carry-over of this material into branch lines is necessary. Carry-over into branch lines can be prevented by making connections from the top of the distribution mains.

Piping must be placed with sufficient flexibility to prevent excessive strain or distortion caused by thermal expansion or sudden changes in pressure. By properly placing pipe supports,

Table 11-2.—Representative Equivalent Length in Pipe Diameters (L/D) of Various Valves and Fittings

Description of Product				Equivalent Length in Pipe Diameters (L/D)	
Globe Valves	Stem Perpendicular to Run	With no obstruction in flat, bevel, or plug-type seat With wing or pin guided disk	Fully open Fully open	340 450	
	Y-Pattern	(No obstruction in flat, bevel, or plug type seat) —With stem 60 degrees from run of pipe line —With stem 45 degrees from run of pipe line	Fully open Fully open	175 145	
	Angle Valves	With no obstruction in flat, bevel, or plug type seat With wing or pin guided disk	Fully open Fully open	145 200	
Gate Valves	Wedge, Disk, Double Disk, or Plug Disk		Fully open Three-quarters open One-half open One-quarter open	13 35 160 900	
	Pulp Stock		Fully open Three-quarters open One-half open One-quarter open	17 50 260 1,200	
	Conduit Pipe Line Gate, Ball, and Plug Valves			Fully open	3**
Check Valves	Conventional Swing		0.5† . . . Fully open	135	
	Clearway Swing		0.5† . . . Fully open	50	
	Globe Lift or Stop; Stem Perpendicular to Run or Y-Pattern		2.0† . . . Fully open	Same as Globe	
Foot Valves with Strainer	Angle Lift or Stop		2.0† . . . Fully open	Same as Angle	
	In-Line Ball	2.5 vertical and 0.25 horizontal†	. . . Fully open	150	
	Foot Valves with Strainer			With poppet lift-type disk With leather-hinged disk	0.3† . . . Fully open 0.4† . . . Fully open	420 75
Butterfly Valves (8-inch and larger)				Fully open	40
Cocks	Straight-Through	Rectangular plug port area equal to 100% of pipe area	Fully open	18	
	Three-Way	Rectangular plug port area equal to 80% of pipe area (fully open)	Flow straight through Flow through branch	44 140	
Fittings	90-Degree Standard Elbow			30	
	45-Degree Standard Elbow			16	
	90-Degree Long Radius Elbow			20	
	90-Degree Street Elbow			50	
	45-Degree Street Elbow			26	
	Square Corner Elbow			57	
	Standard Tee	With flow through run With flow through branch		20 60	
Close Pattern Return Bend				50	
**Exact equivalent length is equal to the length between flange faces or welding ends.				†Minimum calculated pressure drop (psi) across valve to provide sufficient flow to lift disk fully.	

Table 11-3.—Loss of Air Pressure in Hose Caused by Friction

Pulsating flow															
Size of hose, coupled at each end (in.)	Gage pressure at line (lb)	Free air (cfm)													
		20	30	40	50	60	70	80	90	100	110	120	130	140	150
		Loss of pressure (psi) in 50 ft. lengths of hose													
1/2	50	1.8	5.0	10.1	18.1										
	60	1.3	4.0	8.4	14.8	23.4									
	70	1.0	3.4	7.0	12.4	20.0	28.4								
	80	0.9	2.8	6.0	10.8	17.4	25.2	34.6							
	90	0.8	2.4	5.4	9.5	14.8	22.0	30.5	41.0						
	100	0.7	2.3	4.8	8.4	13.3	19.3	27.2	36.6						
	110	0.6	2.0	4.3	7.6	12.0	17.6	24.6	33.3	44.5					
3/4	50	0.4	0.8	1.5	2.4	3.5	4.4	6.5	8.5	11.4	14.2				
	60	0.3	0.6	1.2	1.9	2.8	3.8	5.2	6.8	8.6	11.2				
	70	0.2	0.5	0.9	1.5	2.3	3.2	4.2	5.5	7.0	8.8	11.0			
	80	0.2	0.5	0.8	1.3	1.9	2.8	3.6	4.7	5.8	7.2	8.8	10.6		
	90	0.2	0.4	0.7	1.1	1.6	2.3	3.1	4.0	5.0	6.2	7.5	9.0		
	100	0.2	0.4	0.5	1.0	1.4	2.0	2.7	3.5	4.4	5.4	6.6	7.9	9.4	11.1
	110	0.1	0.3	0.4	0.9	1.3	1.8	2.4	3.1	3.9	4.9	5.9	7.1	8.4	9.9
1	50	0.1	0.2	0.3	0.5	0.8	1.1	1.5	2.0	2.6	3.5	4.9	7.0	...	...
	60	0.1	0.2	0.3	0.4	0.6	0.8	1.2	1.5	2.0	2.6	3.3	4.2	5.5	7.2
	70	...	0.1	0.2	0.4	0.5	0.7	1.0	1.3	1.6	2.0	2.5	3.1	3.8	4.7
	80	...	0.1	0.2	0.3	0.5	0.7	0.8	1.1	1.4	1.7	2.0	2.4	2.7	3.5
	90	...	0.1	0.2	0.3	0.4	0.6	0.7	0.9	1.2	1.4	1.7	2.0	2.4	2.8
	100	...	0.1	0.2	0.2	0.4	0.5	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4
	110	...	0.1	0.2	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.8	2.1
1-1/4	50	...	...	0.1	0.2	0.2	0.3	0.4	0.5	0.7	1.1	...	...	...	...
	60	...	...	...	0.1	0.2	0.3	0.3	0.5	0.6	0.8	1.0	1.2	1.5	...
	70	...	...	...	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.7	0.8	1.0	1.3
	80	...	...	...	...	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0
	90	...	...	...	...	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8
	100	...	...	...	...	...	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7
	110	...	...	...	...	...	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6
1-1/2	50	...	...	...	...	...	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.6
	60	...	...	...	...	...	...	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5
	70	...	...	...	...	...	...	...	0.1	0.2	0.2	0.2	0.3	0.3	0.4
	80	...	...	...	...	...	...	...	...	0.1	0.2	0.2	0.2	0.3	0.4
	90	...	...	...	...	...	...	...	...	...	0.1	0.2	0.2	0.2	0.3
	100	...	...	...	...	...	...	...	...	...	...	0.1	0.2	0.2	0.2
	110	...	...	...	...	...	...	...	...	...	...	0.1	0.2	0.2	0.2
(1 inch = 25.4 mm, 1 CFM = 0.0283 mm ³ /min, 1 psi = 6.90 kPa, 50 feet = 15.2 m)															

as shown in table 11-4, movement of pipe can be accounted for. In addition, piping should be supported at all changes in direction and load concentrations, such as heavy valves.

There are many other considerations in the layout of compressed air systems, which are beyond the scope of this manual. Refer to NAVFAC DM 3-5, *Compressed Air and Vacuum Systems*, for further information.

TEST PROCEDURES

After installation, the compressed air system must undergo testing. Generally, all piping and

pressurized components should be tested at 150 percent of maximum working pressure. When testing, use clean, dry air or nitrogen. The system should be held at test pressure without loss for at least 4 hours.

MAINTENANCE REQUIREMENTS

As with any system, preventive maintenance conducted on a scheduled basis is an important factor in providing reliable service. Breakdown maintenance causes interruption in services that

Table 11-4.—Maximum Span for Pipe

DIAMETER INCHES	STD. WT. STEEL PIPE 40 S	COPPER TUBE TYPE K
1/2	5'-0"	3'-9"
3/4	5'-9"	4'-3"
1	6'-6"	5'-0"
1-1/2	7'-6"	5'-9"
2	8'-6"	6'-6"
2-1/2	9'-3"	7'-3"
3	10'-3"	7'-9"
3-1/2	11'-0"	8'-3"
4	11'-6"	9'-0"
5	12'-9"	10'-0"
6	13'-9"	10'-9"
8	15'-6"	
10	17'-0"	
12	18'-3"	

(1 inch = 25.4 mm, 1 foot = 0.3048 m)

prove costly to the Navy. It also requires more extensive repair to system components. As a senior Utilitiesman, you will be required to coordinate maintenance efforts. An understanding of the maintenance needed for each component will aid you in carrying out this type of duty.

PRIME MOVER MAINTENANCE

Air compressors can be driven by diesel, gasoline, and electrical prime movers. These power-producing equipments require the same maintenance as any prime mover used to drive other equipment encountered by the Utilitiesman.

A definite lubrication schedule should be established. Normal oil levels in engines must be maintained at all times, using lubricants recommended by the manufacturer. The frequency of oil changes is dependent upon the severity of service, atmospheric dust, and dirt. These factors will also affect the air filter and, in the case of electrical motors, the need for regular lubrication of bearings.

Daily operator maintenance will prevent most major breakdowns. Following the manufacturer's suggested maintenance requirements will reduce downtime caused by prime mover failure.

AIR COMPRESSOR MAINTENANCE

Taking into consideration the many types of air compressors the Utilitiesman may encounter in the field, it would be impossible to cover all maintenance requirements of air compressors in this section. Several common factors do apply to all compressors.

The establishment of a lubrication schedule is at the top of the list for ensuring trouble-free operation of compressors. A definite schedule and assignment of responsibility to maintenance personnel to follow the schedule is required. The manufacturer's manual will establish minimum requirements that should be followed.

Bearings, packings, seals, and clearances between moving parts must be within manufacturer's specifications and included on the maintenance schedule. Many compressors allow for adjustments while others will require overhaul when clearances are exceeded.

Visual inspections for dust, dirt, or leaks will provide early detection of possible maintenance requirements. Operator maintenance, however, when properly conducted, will catch and correct potential problems early. Ensure all your operators are checked out on their equipment,

including the ability to detect sounds that indicate possible internal troubles.

In all cases have a manufacturer's manual handy and follow its recommendations for maintenance.

AUXILIARY EQUIPMENT MAINTENANCE

All auxiliary equipment that services the air compressor or is serviced by the compressor will require periodic scheduled maintenance.

Air filters should be checked and cleaned at least once a month. Silencers should be checked semiannually for corrosion, paint, and gasket damage. Intercoolers and aftercoolers need to be inspected for scale buildup in hubs, leaks, and so forth. In general, all auxiliary equipment must be placed on a schedule for inspection and periodic maintenance.

DISTRIBUTION SYSTEM MAINTENANCE

Distribution systems require a minimum of maintenance. Checking valve operation, hose connectors, draining condensation (manual or automatic), protecting pipe from damage, and repairing leaks are the common considerations in a maintenance plan.

Procedures applicable to the preventive maintenance schedules, inspections, and record-keeping for compressed air plants can be found in NAVFAC P-322, *Inspection for Maintenance of Public Works and Public Utilities*.

For more involved technical maintenance, such as overhauls, make sure competent personnel are trained before they are needed. Again, follow the manufacturer's manuals as a sure way to repair any air compressor or component.

REFERENCES

- Compressed Air and Vacuum Systems*, NAVFAC DM-3.5, Naval Facilities Engineering Command, Alexandria, Va., March 1983.
- Maintenance of Steam, Hot Water and Compressed Air Distribution Systems*, NAVDOCKS M-209, NAVFAC, Alexandria, Va., March 1966.
- Operation and Maintenance of Air Compressor Plants*, NAVDOCKS MO-206, NAVFAC, Alexandria, Va., January 1964.

CHAPTER 12

BOILERS

Learning Objective: Identify the procedures required for the installation, operation, and maintenance of boiler plants.

As a senior Utilitiesman, you will be expected to analyze situations that task your knowledge and expertise in installing, operating, and maintaining boilers.

The most common type of boiler you can expect to encounter is the scotch marine-type boiler. "Scotch marine" is a generic term that identifies a boiler with a furnace, which forms an integral part of the boiler assembly. This configuration permits very compact construction requiring only a small space for the capacity produced. Scotch marine boilers are package units consisting of the pressure vessel, burner, controls, draft fan, draft controls, and other components assembled into a fully factory-fire-tested unit. Most are tested by the manufacturer as individual units before being shipped to customers. This provides, in each case, a preengineered unit ready for quick installation and connection to services.

As a first class petty officer, you will be expected to supervise other personnel in the installation, operation, and maintenance of boilers. As a chief petty officer, you will be responsible for the overall management of these plants. This chapter provides insight into many of the skills that you must develop to be a proficient supervisor/manager of a boiler plant.

INSTALLATION OF BOILERS

When you are preparing to install a boiler, you must consider two basic factors—site location and accessories and fittings. This section discusses each of these items. Remember, the most important single point in the successful operation of a boiler is its proper installation. Always refer to the manufacturer's manuals, and follow your prints and specifications closely. By being thorough in your planning and execution of plans, you can

prevent many future problems for operators and maintenance personnel.

SITE SELECTION

Careful consideration must be given to the selection of a site for the construction of any boiler plant. Primarily, the cost in materials, manpower, and equipment is the most important factor affecting this selection. This cost is generally reduced by locating the plant site as close as possible to the largest load demand facility, such as a galley or laundry.

Location

When selecting the site, you must also take into account other factors, such as the availability of water, electricity, fuel, and the capability of the site to drain either naturally or by mechanical means. Also, high pedestrian and vehicle traffic areas should be avoided for safety reasons. Another item to consider is noise level. Noise pollution may cause discomfort for personnel, especially if the site being considered is adjacent to a berthing area.

These are factors you must consider when you become involved in selecting a boiler plant site. Each situation may include all, part, or more than these factors. You must look at each installation and evaluate the needs of that job.

Boiler Foundation

Constructing the foundation or platform a boiler sits on requires skilled engineering and development. Manufacturer's specifications must be adhered to. Boilers may vary in wet weight from 1.5 tons to more than 20 tons. A substantial

foundation that can withstand the weight and absorb vibration is a must.

Reinforced concrete slabs with runners provided for placing and anchoring the boiler are generally used. The runners should provide a level, uniform support and be of sufficient height to allow for bottom-side maintenance and the installation of piping. A raised platform also provides easier access for boiler room cleanup.

Generally, a sump is constructed in the slab between the runners to provide a catchment area for boiler blowdown or draining of the boiler. This sump is then drained from the building to a suitable dispersal point.

Boiler Room

When considering the requirements of sheltering a boiler, you must take many things into account. You must ensure there is enough room for the boiler and all of the accessory equipment. This accessory equipment may include condensate tanks and pumps, chemical feeders, water makeup tanks and feeders, and blowdown tanks.

The boiler room must also be large enough to allow for boiler maintenance. Allowances for retubing and for removing and replacing the boiler must be made. The tube length of a boiler may be from 2 feet 6 inches to at least 10 feet, and possibly longer. To facilitate the removal of these tubes, the boiler room must be long enough or must have a door located behind the boiler. The most important thing to check is the manufacturer's specifications, which gives the proper dimensions for locating the boiler.

Fresh air inlets and louvers to allow fresh air to move across the boiler are needed. This fresh air entering the boiler room is required not only to remove excess heat from the boiler room, but also to provide adequate makeup air for combination. Table 12-1 gives the general recommended dimensions for fresh air inlets.

When you are planning and building a boiler room, you must always consider the boiler requirements, maintenance requirements, manufacturer's recommendations, and the boiler operator's needs.

ACCESSORIES

As you study this section, refer to figure 12-1 for identification of the accessory equipment

Table 12-1.—Recommended Dimensions for Fresh Air

Total Boiler Horsepower	Equivalent Free Area Opening
30	15" × 18"
40	18" × 20"
50	18" × 25"
60	20" × 27"
75	25" × 27"
80	25" × 29"
100	28" × 32"
125	32" × 35"
150	35" × 40"
200	40" × 45"

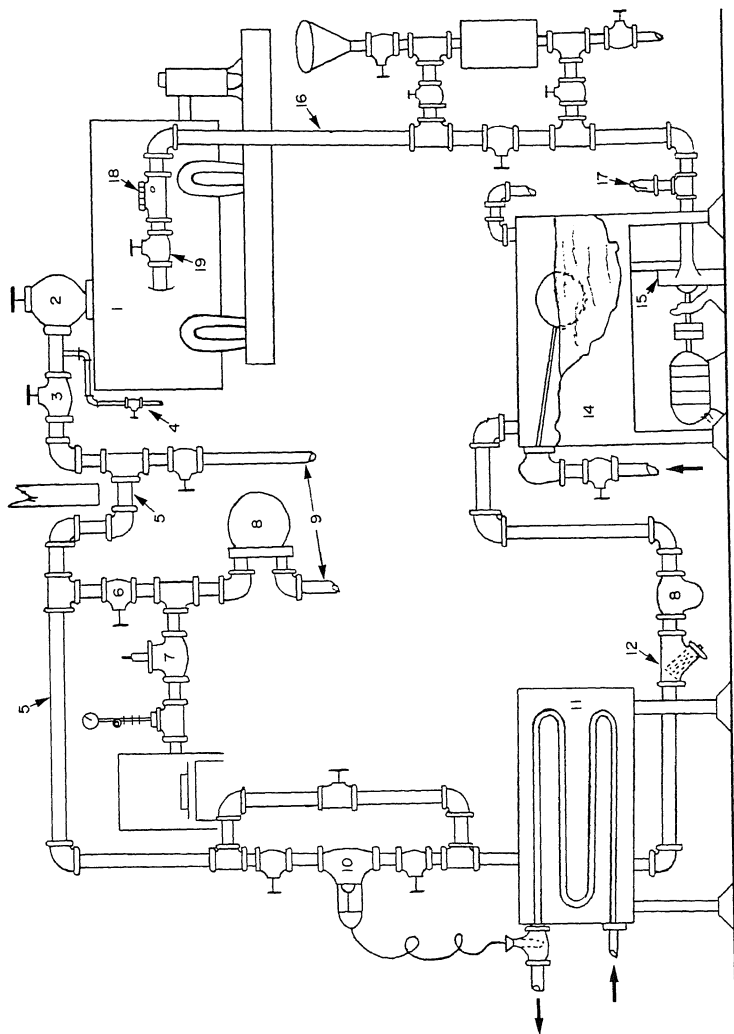
numbered 1 through 19. An explanation of each numbered item follows.

1. **Boiler**—A boiler is a closed vessel in which steam is generated or water is heated as a result of the combustion of fuel.

2. **Main steam-stop valve**—This valve is located at the steam outlet of the boiler. Only one such valve is required when a system is being supplied by an independent boiler. The purpose of this valve is to put the boiler on the line or to secure it. The main steam-stop valve should never be used for throttling; it's either fully open (backed off one-fourth turn) or fully closed. The ASME code requires that this valve be of the outside screw and yoke rising spindle-type if it is over 2 inches in size. The reason for this is that such a valve permits the operator to distinguish the position (open or closed) by sight.

3. **Guard valve (second steam stop)**—When two or more boilers are connected to a common header, the steam connection from each boiler having a manhole opening (bodily entrance to watersides) must be fitted with two stop valves. The purpose of this valve is to serve as a guard or backup to the main steam-stop valve, should a person be required to enter a boiler that is isolated from the system for repair or maintenance.

4. **Daylight (drain) valve**—Whenever two steam stops (main and guard) are required, then the system must be provided with a daylight valve installed between them. The discharge from this valve must be visible to the operator while manipulating the valve. This valve should be opened only when the main and guard valves are closed; thus, it can be used to indicate if either valve is leaking and if either valve requires repair to provide a positive shutoff.



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Figure 12-1.—Boiler accessory equipment.

5. **Main steam line**—When a system is supplied by an independent boiler, the line that conveys steam from the boiler to all branch or distribution lines is considered to be the main. When a system is supplied by a bank of boilers connected into the same header, the line(s) conveying steam for the boiler(s) to the header is considered to be the main.

6. **Root valve**—These valves are installed on branch or distribution lines (just off main steam line) to enable isolation of equipment or areas from the source of pressure by securing only one valve. Thus, this valve normally serves as an emergency shutoff for individual areas or pieces of equipment. This valve is usually of the gate-type design and should always be either fully opened (backed off one-fourth turn) or fully closed.

7. **Pressure regulating valve (PRV)**—This type of valve is normally installed as close as practical (after a reducing station) to the equipment or area it serves as the result of requiring a lower pressure than line pressure. Coppers, dishwashers, steam chests, turbines, and so forth, are a few pieces of equipment that generally require the use of PRVs.

8. **Steam traps**—These devices automatically drain condensate and prevent the passage of steam. Accumulation of condensate may seriously affect the efficiency of a system by decreasing the capacity for heat transmission. These devices are installed on the discharge side of steam-heating or cooking equipment, at dead ends, low points, or at regular intervals throughout a steam system (for automatic drip legs).

9. **Drip legs**—Drip legs are usually provided throughout a system where condensation is most likely to take place, such as at dead ends, low points, the bottom of all risers, at intervals of not over 200 feet for horizontally pitched (accessible) pipe, and at intervals of not over 350 feet for buried or inaccessible pipe. Drip legs are provided to remove condensate, generally through the use of steam traps; however, manual drain valves may be used. The disadvantage to manual drip legs is that they must be accessible and manually operated on a routine basis.

10. **Temperature regulating valve (TRV)**—This valve is installed near equipment that requires temperature regulation, such as a heat exchanger.

The TRV consists of a valve, capillary tubing, and a sensing element (thermal bulb). The valve portion is installed in the steam or hot-water line supplying the heat, and the sensing element is inserted at the point where the temperature is to be controlled, such as at the hot-water discharge side of the heat exchanger. The TRV is always in the open position unless activated by pressure resulting from an increase in temperature. The TRV functions as follows: With the valve in the open position, the source of heat is permitted to flow, transferring its heat to the product being controlled. As the controlled product is heated, the gases within the sensing element are also heated. As heat is absorbed, the gases begin to expand; thus, a pressure is created up through the capillary tube to the upper portion of the valve, which houses a bellows or diaphragm that is directly connected to the valve stem. When the desired temperature is reached, through design features of the TRV, sufficient force is applied to the valve stem to fully close the valve. Once the temperature of the controlled product lowers, the gases (within the sensing element, cap tube, and upper portion of valve) cool and contract. This lowers the pressure applied to the bellows or diaphragm and allows spring tension to open the valve, permitting the source of heat to flow through the valve again.

11. **Heat exchanger**—This device is an unfired, pressure vessel with a shell that is equipped with a heat supply inlet and outlet and a tube nest that is fitted with a water or oil inlet and outlet. The heat exchanger should be located as close as practical to the source for which it is going to supply heated water or oil. For example, it should be located near the boiler for which it is going to be used as a feedwater heater, or near a head for which it is going to supply hot water for showers, lavatories, and so on. The source of heat supply for an exchanger may be steam, hot water, or electricity (such as the heating elements in domestic hot-water heaters). The function of the heat exchanger is as follows: The product (water or oil being heated) flows through the tubes that are surrounded by the heat source (steam or hot water). Heat is absorbed through the tube walls by the product through means of conduction. The temperature of the product and the flow of the heat source is controlled by the temperature-regulating valve. When a larger storage space is required for the product, the heat source may travel through the tubes that are surrounded by the product.



12. **Strainer**—In-line strainers should be installed in steam or water lines just ahead of PRVs, TRVs, steam traps, and pumps. Strainers are used to prevent malfunctions or costly damage to vital equipment and system components by trapping foreign matter such as rust, scale, and dirt, as the flow (steam or water) is channeled through the strainer. The strainer is fitted with a bucket-type screen, which is constructed of thin sheet metal, usually of bronze, Monel, or stainless steel. The strainer screen may be removed for cleaning; however, it is better that you have a piping arrangement that allows you to eliminate any foreign matter while the system is in operation.

13. **Condensate line**—Condensate return lines extend from the discharge side of steam traps (used throughout a system) to the boiler's condensate or combination condensate/makeup feedwater tank. Condensate lines convey condensed steam back through the system for reuse; therefore, less (raw) feedwater makeup is required. Thus, the cost of treating the water is lowered, and the boiler efficiency is raised because the condensate is already preheated. This requires less firing of the boiler to reach its desired pressure or temperature.

14. **Condensate/makeup tank**—This tank is normally installed as close to the boiler as practical and at a level higher than the boiler feed pump's suction. The purpose of this tank is to provide a storage space for condensate (returned) and makeup feedwater (required to compensate difference in demand and amount of condensate returned). This tank also vents noncondensable gases to the atmosphere and provides a positive suction and supply of feedwater to the boiler's feedwater pump upon demand. The float-operated valve admits raw (untreated) water into the tank when there is insufficient condensate returned to maintain a proper level.

15. **Feed pump**—The purpose of the feed pump is to supply water to the boiler as required. This pump must be capable of pumping against the operating pressure of the boiler. The feed pump is activated by either an automatic, water-level control or a manual control. It takes its suction from the condensate/makeup tank and feeds the boiler upon demand. The feed pump is installed between the condensate/makeup tank and the boiler shell or steam

drum. Centrifugal, reciprocating, and jet pumps are used for boiler feed purposes, with the centrifugal type being used almost exclusively. Any boiler having 500 or more square feet of water-heating surface must have at least two means of feeding water. The steam injector normally suffices as the second means of feeding under emergency or standby conditions.

16. **Feedwater pipe (external)**—This line extends from the discharge side of the feed pump to the point at which it connects either to the boiler shell or to the steam drum. (This connection is normally below the steaming water level.) The purpose of this line is to convey feedwater to the boiler and provide a means (place) for installing other required accessories (relief, check, and stop valves). This line is subject to greater pressure when the boiler is calling for water.

17. **Relief valve**—This valve should be installed between the feed pump and the nearest shutoff valve used in the external feed line. Should the external feed line be secured and the feed pump accidentally started, a ruptured line or serious damage to the feed pump could occur if there were no relief valve. Relief valves are designed to open (gradually as the pressure increases) automatically to prevent pressures from increasing beyond a safe operating limit.

18. **Feed check valve (swing)**—Such a valve should be installed on the external feed line (near the boiler) between the feed stop and the feed pump. The purpose of this valve is to eliminate any back pressure (boiler-operating pressure) on the external feed system during the intermittent securing (off cycle) of the feed pump.

19. **Feed stop valve**—This valve is installed in the external feed line (as close to the boiler as possible) between the boiler shell or steam drum and the feed check valve. The purpose of this valve is to permit or prevent the flow of water to the boiler and should be used either in the fully opened (backed off one-fourth turn) or closed position. When a globe-type valve is used as a feed stop, the ASME code requires that the feedwater must flow so as to enter (pass through) the valve under its disc.

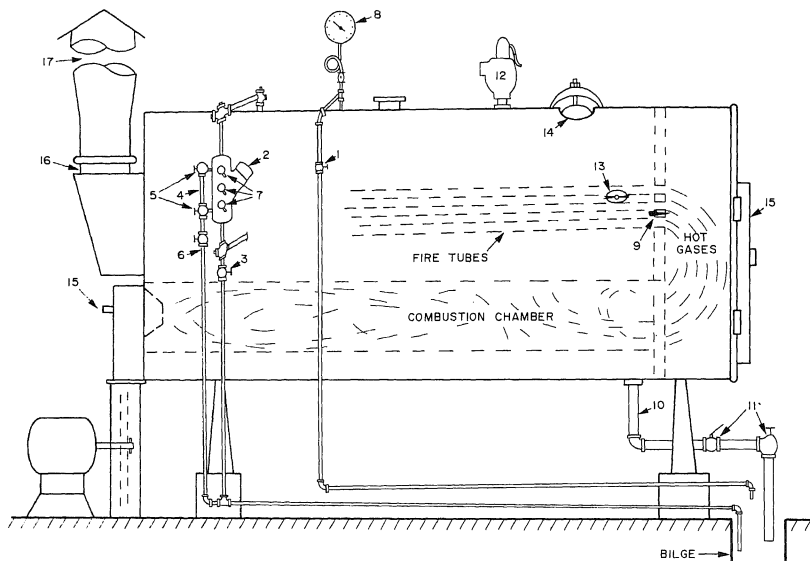


Figure 12-2.—Boiler fittings.

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FITTINGS

As you study this section, refer to figure 12-2 for identification of the boiler fittings numbered 1 through 17. An explanation of each numbered item follows.

1. **Air cock**—This valve is installed in such a manner as to be connected to the uppermost steam space of a boiler shell or steam drum. The air cock is installed on boilers for the following three purposes: (1) to allow air to escape while a boiler is initially being filled with water (air cock should be open); (2) to permit air to escape while steam is initially being raised on a boiler (air cock should be open until sufficient steam has been generated to displace the air in the steam space, and then closed); and (3) to allow air to enter a boiler when it is being drained.

2. **Water column**—This fitting is mounted on either a boiler shell or steam drum adjacent to the steaming water level. Water columns can be identified as being hollow vessels constructed of steel or malleable iron, fitted with gauge glass and try-cock connections. Many designs are provided with various feedwater-level controls. The water column is used for the purpose of steadying the water level in the gauge glass (through the reservoir capacity of the column). It also serves as a sediment chamber that minimizes obstruction of the small diameter gauge glass connections. The ASME code requires that the column be connected to the steam and water spaces with a minimum size pipe and fittings of 1 inch and that each right-angle turn be made with a cross to aid in inspection and cleaning. The steam connection from the column must connect into the uppermost steam space of the boiler shell or steam drum, and the waterside connection must be made at least

6 inches below the lowest permissible water level. The lowest permissible water level is defined as being the lowest level at which a boiler may operate without danger of overheating any part of the boiler. See figure 12-3.

3. Column blowdown line and valve—The line can be identified as being the extension from the bottom leg of the cross (used in connecting the watersides of a column to the boiler) to either a tank, bilge, or blowdown pit. The valve is installed within the blowdown line, normally just below the column itself, so as to be readily distinguishable as the column blowdown valve. This valve should be of the gate-type design so as not to interfere with the flow (scale, sediment, and so forth) during blowdown. The purpose of the valve and line arrangement is to permit

manual removal of sediment and scale from the column and its piping through conveying this waste to a tank, bilge, or blowdown pit. The ASME code specifies a minimum permissible size of three-fourth of an inch for the blowdown line and valve.

4. Gauge glass—These fittings are installed so as to be located at the steaming water level. These glasses may be attached to (or mounted on) either the water column, boiler shell, or steam drum. The purpose of the gauge glass is to provide a visual means of checking the water level being maintained within the vessel. The ASME code stipulates that the minimum permissible size for a gauge glass (cylinder type) is one-half inch; boilers operating at 400 psi of pressure (or greater) must have at least two gauge glasses installed; and

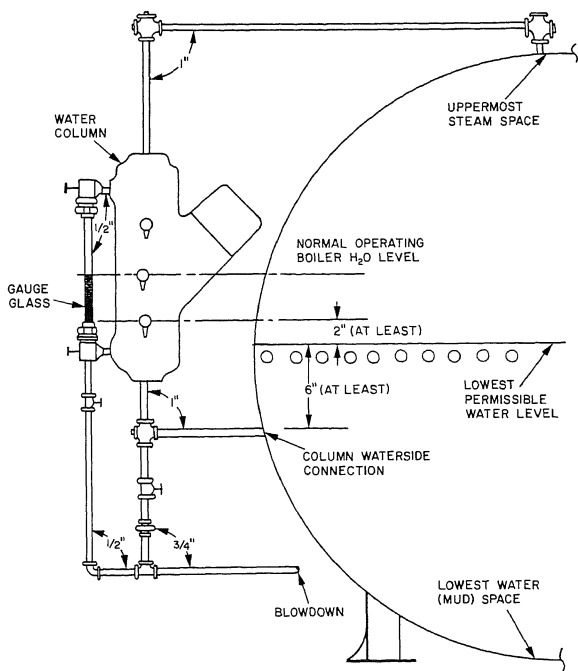


Figure 12-3.—Water column.

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the lowest visible portion of a gauge glass must be at least 2 inches above the lowest permissible water level.

5. Gauge glass shutoff valves.—These valves (special fittings) are installed at the upper and lower ends of a gauge glass, which permits an indirect connection of the glass to a water column, boiler shell, or steam drum. These valves are of the angle-globe type of design and are sometimes fitted with an automatic shutoff device, usually consisting of a nonferrous ball that functions to secure or prevent the escape of steam and water should the gauge glass break while the boiler is under pressure. These valves also provide a means for securing the steam and water ports. This enables the operator to replace the glass (broken, stained, chipped, or defective in some other way) while the boiler is in service or operating. The ASME code stipulates that these valves be not less than one-half inch in size.

6. Glass blowdown line and valve.—The line can be identified as the extension from the bottom gauge glass shutoff valve to either a tank, bilge, or blowdown pit. The valve is normally installed just below the gauge glass, so as to be readily distinguishable as the gauge glass blowdown valve. This valve and line arrangement permits the operator to visually detect partial blockage within the gauge glass connections to the boiler. When the boiler is under pressure and the glass is blowdown, the water level should return promptly when the valve is secured. If the level does not return promptly, this is a good indication of a partial blockage in the gauge glass connection(s).

7. Try-cocks.—These cocks may be installed on either a water column, boiler shell, or steam drum. If only two cocks are used, they are located slightly above and below the steaming water level. If three cocks are employed, they are located above, below, and at the approximate steaming water level. These cocks are of the angle-globe or needle-valve type of design, either of which is fitted with a threaded installation connection and an unthreaded drip port or discharge. The purpose of these cocks is to prove the water level within a vessel and to check the accuracy of a boiler's gauge glass(es). The ASME code stipulates that a boiler with a diameter not exceeding 36 inches or one with a heating surface not exceeding 100 square feet need only be provided with two try-cocks in conjunction with a single gauge glass. On the other hand, if this same boiler is equipped with two mounted gauge glasses, the code stipulates that boilers exceeding 36 inches in

diameter or 100 square feet of heating surface are required to have at least three try-cocks installed, regardless of the number of gauge glasses.

8. Pressure gauge.—Each boiler is equipped with a pressure gauge that serves as a means for measuring the pressure (and determining the boiler point) within the boiler. Pressure gauges should be installed or located in a well-lighted area (so as to be easily read) and connected to the boiler's uppermost steam space. The gauge is connected to a siphon (pigtail) having a capacity large enough to fill the tube within the gauge during operation. This gauge should be installed so that it cannot be secured except by a cock installed near the gauge (preferably just below the siphon). When the piping connecting the gauge to the boiler is over 10 feet long, the cock may be provided with a position-indicating type of handle. The dial on a pressure gauge is usually graduated so that it reads approximately twice the pressure at which the safety valve is set to pipe. It should never read less than 1 1/2 times this pressure. Gauges should be tested semiannually and anytime there is a reason to doubt their accuracy.

9. Fusible plugs.—Some boilers are equipped with these fittings to provide added protection against low water by warning the operator with a hissing noise when the tin, copper, and lead core is melted out. There are two types, fire-actuated and steam-actuated plugs, both of which are directly or indirectly connected at the lowest permissible water level. It is not necessary to take the boiler out of service to replace the steam-actuated type; however, it is necessary to take the boiler out of service when the fire-actuated type is blown or melted. These plugs should be replaced yearly, whether melted out or not. Always use new plugs, and never refill old casings for reuse.

10. Bottom blowdown line.—This line is located and identified as being the line connected to the lowest water space of a vessel (either to the boiler's shell, drum, or header) that extends to either a tank, bilge, or blowdown pit. The purpose of this line is to convey (blowdown) sludge, sediment, excessive chemicals, and water from the boiler to either a tank, bilge, or blowdown pit. According to the ASME code, the minimum size blowdown pipe and fittings for boilers having 100 square feet (or less) of heating surface is three-fourths of an inch. Boilers having heating surfaces in excess of 100 square feet must be provided with blowdown piping and fittings of at least 1 inch and no more than 2 1/2 inches in diameter.

11. Bottom blowdown valves—These valves are installed in the bottom blowdown line. Every boiler is required, by the ASME code, to have at least one slow-opening bottom blowdown valve. The code defines a slow-opening valve as one requiring at least 5 full 360-degree turns between the fully opened and closed positions. Boilers that operate at pressures exceeding 100 psi must be provided with two bottom blowdown valves. This valve arrangement may be either two slow-opening valves or a slow-opening and quick-opening valve properly installed. The quick-opening valve (usually of the cock or plug type of design) must be capable of being fully opened or closed with one-fourth turn of its operating mechanism. This type of valve can be used only if the plug is held in place by a gland or guard with the end of the plug being distinctively marked in line with the passage (position indicating). The purpose of the slow-opening bottom blowdown valve is to prevent too rapid a fluctuation on holding or securing a blowdown. The quick-opening bottom blowdown valve is used to permit emergency securing (one-fourth turn to fully close) and positive shutoffs. Due to its design, this valve is more apt to cut through accumulated sludge and sediment that could prevent a slow-opening valve from closing completely. To avoid shock to the piping and possible injury to personnel when blowing down a boiler, open the quick-opening valve first, then the slow-opening valve. To secure from blowing down, close the valves in reverse order. When both slow- and quick-opening valves are used for blowdown control, the quick-opening valve should be located between the slow-opening valve and the boiler, with the slow-opening valve installed between the quick-opening valve and the tank, bilge, or blowdown pit.

12. Safety valve—This valve is installed and directly connected to a vessel's uppermost steam space without any intervening valve or stop between it and the boiler. The safety valve is considered the most important of boiler fittings; and its construction, installation, and performance are rigidly prescribed in the boiler code. The purpose of this fitting is to prevent pressure within the boiler from increasing beyond the safe operating limit. According to the ASME code, every boiler must be provided with at least one safety valve. If a boiler has more than 500 square feet of heating surface, two or more safety valves are required. At 30-day (monthly) intervals, each safety valve should be manually lifted to blow any dirt away from its seat and to prevent

the disc from sticking in place. When manually lifting the valve for this purpose, you should ensure that the boiler pressure is at least 75% of that at which the valve is set to pop. You should do this to ensure all foreign matter is blown out from around the seat, thereby preventing leakage after the valve is secured. Adjustments and sealing of safety valves should be performed only by authorized personnel, such as qualified boiler inspectors and factory representatives.

13. Handhole plates—These plates are located or installed so as to conform to ASME construction code specifications, which vary considerably with each particular type of boiler. Each of these plate assemblies can be identified as being elliptical or round in shape (plate portion) and consisting of a plate, gasket, yoke, and nut. Handhole plates are provided throughout various areas of a boiler shell or header for the purpose of providing access (either visual or hand and arm entrance) to a boiler's watersides for inspection, maintenance, and repair work.

14. Manhole plates—These fittings can be identified as being elliptical or round in shape, approximately 5 to 6 times as large as handhole plates. Manhole plates consist of a plate, gasket, two yokes, and two nuts. The purpose of this type of plate is to provide access (bodily) to a boiler's watersides for inspection, maintenance, and repair work.

15. Access door—These doors provide access to the combustion chamber and firesides of a boiler for inspection, maintenance, and repair work. These doors can be identified as being round, square, or rectangular in shape. Those of the smaller types are normally fitted with handles for manual removal, whereas those of the larger type or design are normally mounted on hinges, which permit them to be swung aside rather than being manually lifted out of place.

16. Breeching—Breechings may be located so as to extend over a boiler, in back of a boiler setting, or even under boiler room floors. Breechings are usually constructed of steel and can be identified as the means provided for connecting a stack to a boiler, with provisions for expansion and contraction.

17. Stacks—Stacks (chimneys) extend from a boiler's breeching to an elevated point in the atmosphere where health and draft requirements are met. Stacks may be constructed of either steel plate, masonry, or reinforced concrete. When of sufficient size, they are provided or equipped with safe climbing devices for inspection, cleaning, and repair purposes. These items are necessary for

discharging the products of combustion at an elevation high enough to comply with health requirements and prevent a nuisance due to low flying smoke, soot, and ash. Stacks provide a draft, which aids combustion and conducts the flue gases through the complete boiler setting (furnace, tubes, and so forth).

INSPECTING AND TESTING

This section discusses inspection and testing of boilers. *Utilitiesman 3 & 2*, NAVEDTRA 10061, chapters 13 and 14, covered the basics of tests that you can normally expect to encounter in the field. You will benefit from a review of those chapters before you go further into this chapter. This section concerns the responsibilities of the supervisor/manager of a boiler plant.

WATERSIDE INSPECTIONS AND TESTS

Boiler watersides must be inspected before and after cleaning and at any other time the maintenance officer considers it advisable. If there is any reason to suspect the presence of hard scale or serious corrosion, some tubes must be removed for a detailed examination. The results of all waterside inspections must be entered in detail on the boiler water treatment logs and on the engineering log.

When watersides are inspected, at least one handhole plate must be opened on each pass of the superheater. The drums and headers must be opened up completely and the internal fittings must be removed. The internal fittings—especially the steam separators and plates—must be marked to indicate their position in the steam drum. If this is not done, it will be extremely hard to reinstall the fittings correctly.

Since a wet boiler usually gives false indications of its real condition, dry out the boiler thoroughly before you begin a waterside inspection. Note and record the general appearance of all visible areas of the boiler watersides. In particular, look for accumulations of sludge and for indications of scale, rust, general corrosion, and oil or grease marks. Insofar as possible, determine the extent of all defects as well as their nature.

When oil contamination is suspected, you can get a better idea of the extent and nature of the contamination by examining the watersides while the boiler is still wet. When inspecting for oil, take

samples of water from the steam drum and from the economizer headers before the boiler is completely emptied. Analysis of these samples should enable you to determine what type of oil contamination (lube oil or fuel oil) has occurred. If the samples do not show any signs of an oil film, it may be that the contaminating oil has not yet reached the boiler. On the other hand, it may be that the oil contamination has been stopped, and all oil has either been deposited or removed by distillation.

To prevent oil contamination of a boiler, the drain inspection tanks must be inspected at least once each hour and more often if there is any reason to suspect that oil contamination may occur. If an oil film or any cloudiness is observed in the contents of a drain inspection tank, the drains must be shifted to the bilges and a search must be started to determine the source of the contamination. When oil appears in the gauge glass of a boiler, a condenser, a deaerating feed tank, or a freshwater drain tank, you can be sure the feed system has been contaminated by oil.

Waterside Inspection of Boiler Tubes

Regular and careful waterside inspection of boiler tubes provides the information required to determine the need for tube renewal, to determine the effectiveness of boiler water treatment and other maintenance procedures, to diagnose boiler operating troubles, to analyze boiler casualties, and, in general, to give an overall picture of the condition of the boiler.

If tubes are removed between inspections, samples of generating tubes and superheater tubes may be saved for inspection by the Board of Inspection and Survey so that additional tubes will not need to be removed at the time of the inspection. Note, however, tubes that have failed in service or have been damaged.

When there is reason to suspect serious or widespread tube damage, or when the condition of the tubes cannot be clearly determined on the basis of a few sample tubes, an "exploring block" of tubes should be cut. The exploring block should be not more than 10 tubes wide, and it must be deep enough to include the tubes in the center row of the tube bank. A superheater tube and an economizer element must also be removed for inspection when the exploring block is cut.

Tube failures generally occur in the outer half of the tube nest as a result of external corrosion just above the water drum. When such failures have occurred, either in operation or under

hydrostatic test, or when the examination of tubes in the exploring block shows that the tube thickness is less than half the original thickness, complete renewal must be made of all tubes from the center row to the outer row (inclusive) over a fore-and-aft length of the tube bank sufficient to completely cover the affected area. This renewal must be made regardless of the condition of the tubes that were not included in the exploring block.

The existence of slight, scattered pitting does not necessarily require the complete retubing of the boiler, even if the thickness of the tubes at some of the pits is less than 50% of the original tube thickness. When pitting is observed, tubes should be split and examined to see whether the pitting is (1) moderately heavy, and (2) general throughout the boiler.

Internal pitting resulting from improper treatment of boiler water is most likely to occur in tubes that receive the most heat (screen tubes, fire row tubes, and so forth) and in areas that are particularly subject to oxygen pitting. In general, oxygen pitting tends to occur most commonly in downcomers, in superheaters, and at the steam drum ends of generating tubes. If active oxygen pits (that is, pits that are still scabbed over, rather than clean) are found when the boiler is inspected, or if oxygen pitting is suspected because of the past operating history of the boiler, one or two tubes should be removed from the areas in which oxygen pitting is most likely to be found.

The tubes thus removed should be split and examined. If as many as 25% of the pits are deeper than 50% of the tube wall thickness, and if at least a few of the pits are deeper than 65% of the tube wall thickness, a sample of about 20 tubes from the screen and last rows of the generating bank should be cut. These tubes should be split and examined, and their condition should be evaluated on the same basis as before. If as many as 25% of the pits are deeper than 50% of the wall thickness, and if at least a few are deeper than 65%, the oxygen pitting is considered to be general throughout the boiler and moderately heavy. With these findings, complete tube renewal should certainly be considered. However, it is possible that complete tube renewal may be postponed in some cases if (1) the boiler can be successfully cleaned by a chemical cleaning, (2) the boiler can successfully withstand a 125% hydrostatic test, and (3) future boiler water treatment, use of blowdown, and laying-up procedures

can be expected to be in strict accordance with NAVFAC requirements.

Before you make a detailed waterside inspection of boiler tubes, you should be familiar with some of the **WATERSIDE CAVITIES** and **SCARS** that can be recognized by visual examination.

LOCALIZED PITTING is the term used to describe scattered pits on the watersides. These pits are usually—though not always—caused by the presence of dissolved oxygen.

WATERSIDE GROOVES are similar to localized pits in some ways, but they are longer and broader than the pits. Waterside grooves tend to occur in the relatively hot bends of the tubes near the water drum; they may also occur on the external surfaces of desuperheater tubes. Some waterside grooves are clean, but most contain islands of heavy corrosion scabs. A typical example of waterside grooving is shown in figure 12-4.

CORROSION FATIGUE FISSURES are deep-walled, canyon-like voids. They have the appearance of being corroded, rather than fractured, and they may be filled with corrosion products. These fissures occur in metal that has been fatigued by repeated stressing, thus making it more subject to corrosion than it would otherwise be.

GENERAL WATERSIDE THINNING can occur if the boiler water alkalinity is too low over a long period of time, if the boiler water alkalinity is too high, or if acid residues are not completely removed from a boiler that has been chemically cleaned. The greatest loss of metal from general waterside thinning tends to occur along the side of the tube that is toward the flame. The entire length of the tube from steam drum to water



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Figure 12-4.—Waterside grooving in a generating tube.



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Figure 12-5.—General waterside thinning.

drum may be affected. Figure 12-5 shows general waterside thinning.

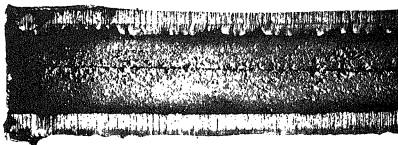
WATERSIDE BURNING may occur if the temperature exceeds about 750 °F in plain carbon steel tubes or about 1,000 °F in most alloy superheater tubes. The effect of waterside burning is the oxidation of the tube metal to a shiny, black, magnetic iron oxide known as high-temperature oxide.

WATERSIDE ABRASION is the term used to describe waterside cavities that result from purely mechanical causes rather than from corrosion. For example, tube brushes or cutters may cause abrasion spots at sharp bends in economizer, superheater, and generating tubes. The surface markings of such abrasions indicate clearly that they result from mechanical abrasion rather than from corrosion.

DIE MARKS appear as remarkably straight and uniform longitudinal scratches or folds on the watersides of the tube. They are the result of faulty fabrication. Die marks, shown in figure 12-6, may extend for the full length of the tube.

Localized corrosion occurs quite often along the die mark.

TUBE CORRUGATION is a peculiar type of heat blistering that occurs when the boiler water is contaminated with oil. Corrugation may consist of closely spaced, small-diameter, hemispherical bulges, as though the tube metal had been softened and then punched from the inside with a blunt instrument. It may also exist as a herring-bone or chevron pattern on the tube wall nearest the flame, as shown in figure 12-7. It is not known exactly why oil contamination of the boiler water tends to cause this patterned corrugation.



98.146

Figure 12-6.—Die marks on the waterside of a tube.

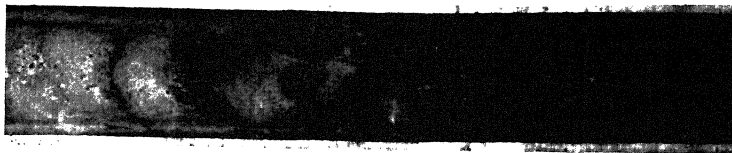


Figure 12-7.—Tube corrugation resulting from oil on watersides.

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Waterside Inspection of Drums and Headers

Whenever a boiler is opened for cleaning and overhaul, the internal surfaces of the drums and headers should be carefully inspected for evidence of cracking. Particular attention must be given to steam drum manhole knuckles, knuckles at corners of drum heads, corners of cross boxes and headers, superheater header vent nozzles, and handhole openings. Any defect found must be recorded in the boiler water treatment log and in the maintenance log. These defects should also be reported to the maintenance office so that appropriate repair action can be taken.

Hydrostatic Tests

Boilers are tested hydrostatically for several different purposes. In each case, it is important to understand why a test is being made and to use—but NOT to exceed—the test pressure specified for that particular purpose. In general, most hydrostatic tests are made at one of three test pressures: boiler design pressure, 125% of design pressure, or 150% of design pressure. Other test pressures may be authorized for certain purposes. For example, a test pressure of 150 psi is required for the hydrostatic test given before a boiler undergoes chemical cleaning.

The hydrostatic test at design pressure is required upon the completion of each general overhaul, cleaning, or repair that affects the boiler or its parts and at any other time when it is considered necessary to test the boiler for leakage. The purpose of the hydrostatic test at design pressure is to prove the tightness of all valves, gaskets, flanged joints, rolled joints, welded joints, and boiler fittings.

The test at 125% of design pressure is required after the renewal of pressure parts, after chemical cleaning of the boiler, after minor welding repairs

to manhole and handhole seats, and after repairs to tube sheets, such as the correction of gouges and out-of-roundness. The “renewal of pressure parts” includes all tube renewals, rolled or welded, except downcomers and superheater support tubes.

The test at 150% of design pressure is required after welding repairs to headers and drums, including tube sheet cracks and nozzle repairs, after drain and vent nipple repairs, and after renewal or rewelding of superheater support tubes and downcomers. The hydrostatic test at 150% of design pressure is basically a test for strength. This test may be (but is not necessarily) required at the 5-year inspection and test.

Before making a hydrostatic test, rinse out the boiler with freshwater. Using at least 50-psi pressure, play the hose onto all surfaces of the steam drum, the tubes, the nipples, and the headers. Examine the boiler carefully for loose scale, dirt, and other deposits. Be SURE that no tools or other objects are left in the boiler.

Remake all joints, being sure that the gaskets and the seating surfaces are clean. Replace the handhole and manhole plates and close up the boiler.

Gag all safety valves. Boiler safety valves must NEVER, under any circumstances, be lifted by hydrostatic pressure. When gagging the safety valves, do not set up on the gag too tightly or you may bend the valve stems. As a rule, the gags should be set up only handtight.

Close all connections on the boiler except to the air vents, the pressure gauges, and the valves of the line through which water is to be pumped to the boiler. Be sure the steam-stop valves are completely closed and that there will be no leakage of water through them.

After all preparations have been made, use the feed pump to fill the boiler completely. After all air has been expelled from the boiler, close the air vents and build up the hydrostatic pressure

required for the particular test you are making. A hand boiler test pump can be used in building up the hydrostatic test pressure. If you do not have a hand test pump, build up the required test pressure by continuing to run the feed pump after the boiler has been filled. In any case, be very careful that you do not exceed the specified test pressure. After the boiler is full, it takes very little additional pumping to build up pressure.

To avoid complications arising from changes in pressure caused by changes in temperature, you should use water that is approximately the same temperature as the boiler and the fireroom. In any case, the temperature of the water must be at least 70°F.

While the hydrostatic pressure is being built up, the boiler should be very carefully checked for signs of strain or deformation. If there is any indication of permanent deformation, stop the hydrostatic test and make the necessary repairs. If it is not possible to make the repairs right away, give a second hydrostatic test, progressing slowly up to 20 psi less than the pressure at which the first test was stopped. If the boiler passes this second test successfully, the new working pressure of the boiler must be two-thirds of the test pressure reached on the second test, and all safety valves must be set accordingly.

Do not make any attempt to set up on leaky handhole or manhole plates until the pressure has been pumped up to within 50 psi of the test pressure. After all manhole and handhole leakage has been remedied, pump the pressure on up to test pressure. Check the pressure drop over a period of time. If all valves have been baked off, the maximum acceptable pressure drop is 1.5% of the test pressure over a period of 4 hours. If connected valves are merely closed and left installed, a drop test will not indicate the true condition of the boiler. The pressure drop test is conducted at boiler design pressure.

A tube seat should not be considered tight unless it is bone dry at the test pressure. Any tube that cannot be made tight under a hydrostatic test should be renewed or rerolled.

If there is an excessive pressure drop when there is only a slight leakage at tube joints, handholes, and manholes, the loss of pressure is almost certainly caused by leakage through valves and fittings. Valves and fittings should be overhauled and made tight.

Five-Year Inspection and Test

At 5-year intervals, each boiler must be inspected for integrity of welds and nozzle connections. Lagging must be removed from drums and headers sufficiently to expose the welded joints and the nozzle connections. The welds and nozzle connections must be inspected visually from both inside and outside. If there is any doubt about the welds, they should be inspected by magnetic particle inspection or dye penetrant inspection. If any area, through examination (visual, magnetic particle, or dye penetrant) reveals that a 150-percent boiler design pressure hydrostatic test is warranted, and the area proves to be tight under test pressure, further investigation of the suspected area should be conducted. The investigation should continue until the true condition of the area is known, and if necessary, appropriate repairs are made.

INSPECTION OF FIRESIDES

Boiler firesides should be inspected for signs of damage to the refractory lining, tubes, protection plates, baffles, seal plates, support plates, and other metal parts. This type of inspection is usually conducted when the boiler is secured for fireside cleaning, but it should be conducted each time the boiler is secured.

Refractory Inspection

Frequent inspection of refractories, together with early repair of any weak or damaged places, can do a lot to prevent refractory failure and to postpone the need for complete renewal. It is a good maintenance practice to inspect the refractories every time the boiler is opened up. Such inspections should be very detailed if you have reason to think the boiler has been operated under severe service conditions—steaming at high rates, burning low-grade or contaminated fuel, or undergoing rapid fluctuations of temperature. Severe conditions cause rapid deterioration of refractories and, therefore, increase the need for frequent inspections.

To make a proper inspection of boiler refractories, you should have considerable knowledge of the causes of refractory deterioration. Also, you should know how to tell the difference between serious damage, which may require a complete renewal of brickwork, and less serious damage, which may be dealt with by patching.

Slagging and spalling are two of the main causes of refractory deterioration. Slag is formed when ash and other unburnable materials react with the brickwork. Although the ash content of fuel oil is low, there is always enough present to damage the refractories. The most damaging slag-forming materials are vanadium salts and sodium chloride.

If the slag that forms on the brickwork would remain in place, it would not cause any particular trouble; however, the slag does not remain in place. Instead, it peels off or melts and runs off, taking some refractory with it and exposing a fresh layer of refractory to further slag attack. When deterioration of the brickwork has progressed until only a 3-inch thickness of firebrick remains, the wall should be replaced. When sufficient slag has accumulated on the deck to cause striking with resultant deposits of carbon, the slag should be removed. If less than 1 1/2 inches of firebrick remain after the slag is removed, the entire deck must be replaced.

Another type of slag that results from using fuel oil that is contaminated is usually more damaging than peeling slag. This type of slag is very glassy in appearance, and when this slag melts, it usually covers the entire wall or deck.

Firebrick shrinkage is another cause of furnace deterioration. True shrinkage (permanent shrinkage) is quite rare in firebrick approved for naval use. However, this defect can occur even in approved firebrick. In any case, it is important to recognize the appearance of true firebrick shrinkage because of the extremely dangerous condition it could create if it should occur. When the firebrick shrinks, the hot-face dimensions of each brick become measurably smaller than the cold-face dimensions. This condition leaves an open space around each brick, and the entire wall or floor becomes loose. A wall or floor having this appearance is DANGEROUS and should be completely renewed as soon as possible.

Also, during your inspection, look for signs of unequal stresses that are caused by rapid raising of the furnace temperature while raising steam too rapidly. Emergencies may arise that require the rapid raising or lowering of furnace temperatures, but it is important to remember that the refractories cannot stand this treatment often. As a rule, you will find that raising the furnace temperature too rapidly causes the firebrick to break at the anchor bolts, and lowering the temperature too rapidly causes deep fractures in the firebrick.

Also, look for signs of mechanical strain caused by poor operation of the boiler. Continued panting or vibration of the boiler can cause a weakened section of the wall to be dislocated so that the bricks fall out onto the furnace floor. Improper oil-air ratio is the most common cause of boiler panting and vibration. Proper operation of the boiler, with particular attention to the correct use of the burners and forced draft blowers, generally prevents panting and vibration of the boiler.

Inspection should also be made of the lower side of the floor pan. Any overheating indicates a loss of insulation and excessive heat penetration. Under normal conditions, the brickwork in a boiler should last for a number of years without complete renewal.

Expansion joints should be inspected often for signs of incomplete closure. It is important to keep the joints free of grog, mortar, and refractory particles so that the joints can close properly when the boiler is fired. You can tell if an expansion joint is closing completely when it is heated by inspecting it when it is cold. If the inside of the expansion joint is light in color when the furnace is cold, the expansion joint is closing properly. If an expansion joint does not close properly when heated, the inside is dark and discolored.

The same method can be used to tell if cracks in refractory materials are closing properly when the furnace is fired. If the cracks are dark, showing that they do not close, they should be repaired.

Since the first firing of a plastic or castable burner front does more damage than any other single firing, the first inspection after installation is a very important one. The unfired burner front may appear to be in perfect condition while actually containing defects of material or workmanship that will show up immediately in the first firing.

After the boiler has steamed for several hours, slabs of plastic about 1/2- to 1-inch thick may separate from the burner's front surface and fall off. This is because the surface layer is more densely rammed during installation than the remainder of the material.

Radial cracks in the burner fronts may be found on the first inspection. These cracks are not harmful. They are caused by stresses resulting from the normal expansion and contraction of the refractory as it is heated and cooled. After the radial cracks occur, the stresses are relieved and there should be no further cracking of this type.

The cracks that eventually result in extensive damage run approximately parallel to the surface

of the burner front, and they are called parallel cracks. Parallel cracks usually appear at or slightly behind the leading edge of the bladed cone. They are not dangerous until they actually loosen pieces of the burner front. Improper installation and boiler operation are usually the cause of parallel cracking.

A slanting crack in the narrow section between the burners sometimes joins a radial crack. When this occurs, pieces of plastic tend to break off. This type of damage can usually be repaired by a plastic patch.

If during your inspection you find that a castable burner front is breaking up after very little service, it is likely that too much water was used in mixing the material during installation. Sometimes the material is already partially set before installation; a common cause of this trouble is that the castable material, while in storage, reacted with moisture in the air and started to set. When castable material sets before it is used, it can never reach full strength.

Castable material is also subject to spalling after several hours of service. The peeling material, usually in 1/8-inch strips, should not be removed unless it is in the burner cone and is interfering with combustion.

If a castable front is chalky or crumbly, find out how deep the condition goes. If no more than the surface can be rubbed off, the burner front is not seriously damaged. Do not remove the crumbly material. The condition is serious only if the burner cone is affected or if the casing shows signs of overheating.

Burner tile should be inspected for loose segments and broken pieces that might cause improper cone angles. The broken or damaged segments can be repaired by patching with plastic fireclay refractory. In some cases a new segment of tile can be installed.

When you inspect boiler refractories, it is a good idea to keep in mind the possibility that damage may occur because of operational problems. Although boilers must occasionally be operated under very severe and damaging conditions, a lot of damage to refractories (and, in fact, to other boiler parts as well) is caused by poor operating procedures that are really not necessary under the circumstances. It may be helpful to show operating personnel any refractory damage that appears to be directly related to poor operation of the boiler.

Tube Inspection

When inspecting the exterior of boiler tubes, look for signs of warping, bulging, sagging, cracking, pitting, scaling, acid corrosion, and other damage. All tube sheets should be inspected for signs of leakage, especially the superheater tube sheet.

Inspection of boilers sometimes shows an unexpected condition in which adjacent boiler tubes are warped in such a way that they touch each other. When this condition exists, the tubes are said to be married. Tube marriages can result either from overheating of the tubes or from stresses developed in the tubes during installation. For the latter reason, newly erected boilers and boilers that have been retubed should always be inspected for tube alignment after the initial period of steaming.

When inspection reveals one or more tube marriages, the decision as to whether or not the married tubes should be renewed should be based on the following considerations:

1. If the tube marriage occurs in screen tubes 1 1/2 inches or larger, or if the furnace side wall or rear wall tubes are bowed, tube replacement is usually required.

2. If 1-inch or 1 1/4-inch tubes in the main bank of generating tubes are married, replacement is usually not required if the tube joints are tight under hydrostatic test.

3. Inspect the external surfaces of the tubes. If they show blistering or other signs of overheating, the tubes should be renewed.

4. Inspect the watersides. Where tube marriages exist, a poor waterside condition may indicate hard scale or oil within the affected tubes. If hard scale or oil does exist, the married tubes should be replaced, and all appropriate steps should be taken to remove the scale or oil from the rest of the boiler. If the condition of the tubes is uncertain, or if a large number of tube marriages have occurred, remove one or more sample tubes, split them, and examine them carefully.

5. Tube marriages may cause gas laning, and gas laning, in turn, may cause local overheating of the inner casing, the bottom part of the economizer, and other parts. Inspect the boiler carefully for signs of local overheating that might have been caused by gas laning resulting from the tube marriages. If the local overheating from this cause is found, renew the married tubes.

6. On single-furnace boilers, a lane more than 1 1/2 inches wide may allow overheating of the superheater and of the superheater supports. If a large lane (1 1/2 tubes wide or wider) exists near the superheater outlet header end of the boiler, the married tubes that caused such a large lane should be renewed.

To identify the cause of the tube failure by visual inspection, you will need to know something about the various ways in which tubes rupture, warp, blister, and otherwise show damage. Tube failures must be reported, and they must be reported in standard terminology. The following sections of this chapter deal with the inspection techniques required for determining the causes of tube failure and with the various ways in which boiler tube damage is classified and identified.

The inspection techniques required for determining the cause of tube failure must naturally vary according to the nature of the problem. For example, a rupture in a fire row tube can usually be described adequately on the basis of simple visual observation, but the cause of damage to a tube that is deep in the tube bank cannot usually be determined without removing the intervening tubes. When a blistered tube suggests a waterside deposit, the nature and extent of the deposit can be determined only by removing and splitting the tube so that the waterside can be examined.

Relatively simple equipment is required for the field inspection of damaged or fouled pressure parts. Equipment for this purpose should include the following: (1) devices for measuring tube diameters, depth of pits, and thickness of deposits; (2) instruments for separating deposits and corrosion products—a sharp knife, a chisel, a steel scribe, or a vise to crack deposits loose from the tube samples; (3) an approved type of portable light; (4) a supply of clean bottles for collecting samples of deposits; and (5) a mirror for viewing relatively inaccessible places.

Many of these items of equipment can be improvised if necessary. For example, a simple gauge for measuring the depth of waterside pits may be made by pushing a straight pin or a paper clip through a 3- by 5-inch card so that the point of the pin or clip projects beyond the card, at right angles to the card. Such an improvised depth gauge is shown in figure 12-8. A section of string can be wrapped around a deformed tube and then laid along a ruler to obtain a measure of tube enlargement or tube thinning. Of course, special tools such as calipers, depth gauges, and scale

thickness indicators give more accurate results and should be used if they are available; but the improvised tools, if used with care, can also give good results.

The classification of boiler tube damage is considered here under four major classifications: (1) fireside cavities and scars, (2) waterside cavities and scars, (3) tube deformities and fractures, and (4) tube deposits.

FIRESIDE CAVITIES AND SCARS on the tube firesides often indicate the reasons for tube failure. The term *circumferential groove* is used to describe the metal loss that occurs in bands or stripes around the circumference of a tube. Fireside grooving of this type often occurs at the header ends of horizontal tubes such as superheater tubes. The most common cause of this damage is leakage from tube seats higher in the tube bank. The grooving occurs as the water runs

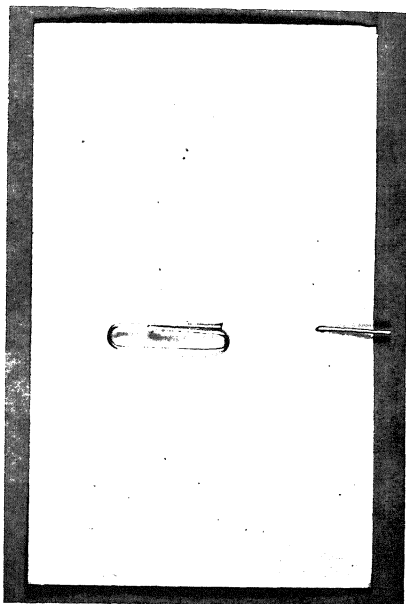


Figure 12-8.—Improvised depth gauge.

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98.137

Figure 12-9.—General fireside circumferential grooving.

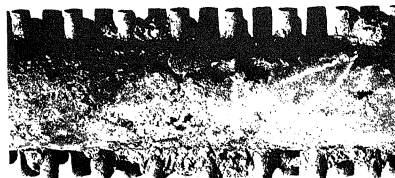
down the header and onto the tube ends, or as it drips directly onto the tubes. This kind of damage is greater on the top of the tube than on the underside, but the groove may extend around the entire circumference.

Fireside circumferential grooving may also occur on vertical generating tubes as a result of thin, damp deposits of soot on horizontal drums or headers. In fact, this kind of grooving can occur in any part of the boiler where leakage provides a sufficient supply of water. Large quantities of water trapped between the water drum and the boiler casing—as, for example, from a serious economizer leak—can produce general fireside grooving around the bottom of the rear generating tubes. An example of this general fireside circumferential grooving is shown in figure 12-9.

CRATERS are deep, irregular, straight-walled cavities in the tube metal. WATER TRACKS are closely related to craters; the tracks consist of wandering, straight-walled, canyon-like cavities in the tube metal. Both cratering and water tracking occur almost exclusively at the header ends of water wall tubes and division wall tubes that are surrounded by refractory; they are caused by water becoming trapped between the tube metal and the surrounding refractory. Water washing of boiler firesides, without proper drying out, is

a frequent cause of cratering and water tracking; however, any leak higher in the boiler can also cause this type of damage. The size of the leak and the angle of the tube upon which the water leaks determine, to a large extent, whether the resulting damage will be circumferential grooving, cratering, or water tracking. Both cratering and water tracking are shown in figure 12-10.

GENERAL FIRESIDE THINNING consists of a uniform loss of metal over a relatively large area on the outside of the tube. Soot corrosion is by far the most common cause of general fireside thinning. The parts that are particularly subject to this kind of damage are superheater



98.138

Figure 12-10.—Fireside cratering and water tracking.

tube ends between the headers and the seal plates, water drum ends of generating tubes, and return bends in economizer tubes. General fireside thinning of a generating tube is shown in figure 12-11.

A rather unusual type of general fireside metal loss sometimes results from the combination of extremely high tube temperatures and the burning of fuel oil that contains vanadium compounds. The vanadium compounds carried in the flame can cause rapid oxidation of metal at high temperatures. This type of damage is unusual in water-cooled parts of the boiler, since critical temperatures are not usually attained. Figure 12-12 shows a stainless steel superheater tube that has suffered this type of general thinning as a result of fuel ash damage.

FIRESIDE BURNING occurs when the rate of heat transfer through the tube wall is so reduced that the metal is overheated. Waterside deposits can cause fireside burning, but most serious fireside burning occurs when a tube becomes steam bound or dry. Figure 12-13 shows the coarse, brittle appearance of tube metal that has suffered fireside burning.

STEAM GOUGING occurs when steam jets out of a hole in an adjacent tube. Steam gouging can be identified by the extremely smooth surface of the cavity, together with the irregular shape of

the cavity. As may be seen in figure 12-14, a steam gouge looks as though the metal has been blasted away and the cavity polished.

TOOL MARKS, such as chisel cuts or hammer scars, can usually be identified without too much trouble. As shown in figure 12-15, tool marks do not resemble corrosion effects in any way.

TUBE DEFORMITIES AND FRACTURES comprise another category of boiler tube damage that covers abnormal bends, blisters, bulges, cracks, warps, sags, and other breaks or distortions. Like the cavities and scars previously discussed, tube deformities and fractures are fairly easy to distinguish by visual observation.



98.139

Figure 12-11.—General fireside thinning of a generating tube.



98.140

Figure 12-12.—General fireside thinning of a stainless steel superheater tube (results of fuel ash damage).



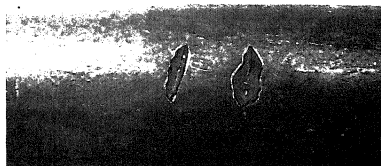
98.141

Figure 12-13.—Fireside burning.



98.142

Figure 12-14.—Fireside steam gauge.



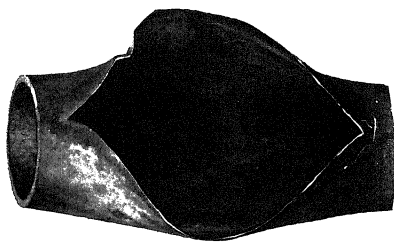
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Figure 12-15.—Fireside tool marks.

The THIN-LIPPED RUPTURE, shown in figure 12-16, is a fairly common tube deformity. The rupture resembles a burst bubble; the open lips are uniformly tapered to sharp, knifelike edges, with no evidence of cracking or irregular tearing of the metal. True thin-lipped ruptures occur in economizer tubes, in generating tubes, and, to a much lesser extent, in superheater tubes. Ruptures of this type indicate that the flow of steam or water was not adequate to absorb the heat to which the tube was exposed; consequently, the tube metal softened and flowed and then burst. Thin-lipped ruptures may be caused by a sudden drop in water level or by tube stoppage from plugs, tools, and so forth, that were accidentally left in the boiler.

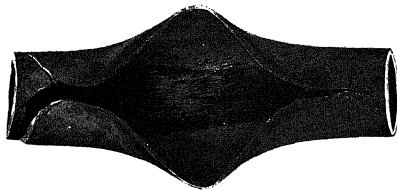
Serious THICK-LIPPED RUPTURES resemble the thin-lipped ruptures except that the edges are thick and ragged rather than tapered and knifelike. Thick-lipped ruptures that occur in mild steel generating tubes indicate milder and more prolonged overheating than the overheating that leads to thin-lipped ruptures. Abnormal firing rates, momentary low water, flame impingement, gas laning, and many other causes can produce mild but prolonged overheating that can eventually lead to thick-lipped ruptures. A typical thick-lipped rupture in a generating tube is shown in figure 12-17.

PERFORATION is the term used to describe any opening in a tube (other than a crack) that is NOT associated with tube enlargement. The most common kind of perforation



98.147

Figure 12-16.—Thin-lipped rupture in a generating tube.



98.148

Figure 12-17.—Thick-lipped rupture in a generating tube.



98.150

Figure 12-18.—Thermal crack in a superheater tube.

is probably the pinhole leak. In many cases, the first evidence of tube failure is a pinhole leak.

THERMAL CRACKS, sometimes called CREEP CRACKS, result from prolonged, mild overheating or repeated short-time overheating. Cracks of this type are found most often in alloy superheater tubes, but they can occur in mild steel tubes as well. The tube is not usually enlarged when a thermal crack exists; the cracked wall has normal thickness, and the break has a dark crystalline appearance. A typical example is shown in figure 12-18.

TUBE ENLARGEMENT of the type shown in figure 12-19 is relatively common in superheater tubes but rare in generating tubes. This uniform enlargement of a portion of the tube is caused by milder overheating than that which produces cracks or ruptures. If an enlarged tube is continued in service, it will almost certainly crack or break.



Figure 12-19.—Enlarged tube.

98.152



Figure 12-20.—Heat blister on a fire row tube.

98.153

HEAT BLISTERS differ from tube enlargements in that they affect only one side of the tube, usually the side toward the fires. Blisters appear as egg-shaped lumps on the fireside. They indicate that the tube has been heated to the softening point and has blown out under boiler pressure. Heat blisters always indicate the presence of waterside deposits. If the deposit is brittle, as scale or baked sludge, blistering breaks the deposit and allows the boiler water to quench the hot metal before the tube bursts. Heat blisters are most commonly found on the fire row generating tubes; they are rarely found on superheater tubes or economizer tubes. A typical heat blister is shown in figure 12-20.

SAGGING is the term applied to tubes that appear to have dropped downward toward the furnace under their own weight. This type of deformation results from semiplastic flow of the tube metal, caused by extremely mild overheating. A momentary condition of low water is probably the most common cause of sagging. If the boiler has been cooled slowly, and if the distortion is not so severe

as to interfere with the designed flow of combustion gases, sagged tubes may still be continued in service.

WARPING is similar to sagging except that the distortion is haphazard rather than in one direction. Warping usually occurs as a result of sudden cooling of the tubes after they have been overheated. Cooling a boiler too rapidly after a low-water casualty is a typical cause of warped tubes.

MELTING can occur as a result of a serious low-water casualty. If the tube temperature becomes high enough, the tube metal actually melts and runs down into the furnace. A cluster of fused tubes that resulted from melting is shown in figure 12-21. Melting of aluminum economizer parts can cause tremendous damage to a boiler. The molten aluminum from overheated economizer parts reacts so violently with the iron oxide coating on the steel tubes below that the heat of the chemical reaction may melt the steel tubes even though the furnace temperature is not high enough to melt them.



Figure 12-21.—Melted cluster of tubes.

98.155



Figure 12-22.—Lamination of a tube wall (fabrication defect).

98.157

MECHANICAL FATIGUE CRACKS occasionally occur in boiler tubes from such purely mechanical processes as flexing. Cracks of this type can usually be identified by a clean, bright break through a major portion of the metal thickness. These cracks begin on the outside circumference of the tube.

TUBE WALL LAMINATION is shown in figure 12-22. This lamination or layering occurs during the fabrication of the tube. It is the most common material defect found in boiler tubes.

FOLDED or UPSET TUBES are a result of defective fabrication. A folded tube is shown in figure 12-23. This defect resembles a heat blister in appearance, but the folded tube shows no wall thinning and has a depression on the side of the tube opposite the bulge.

STRETCHED or NECKED TUBES are also a result of defective fabrication. A stretched or necked tube is shown in figure 12-24.

FIRESIDE TUBE DEPOSITS can produce many of the scars and deformities just described. Basically, tube deposits cause tube failure because they lead to localized overheating of the tube



98.158

Figure 12-23.—Tube fold (fabrication defect).



98.159

Figure 12-24.—Stretched or necked tube (fabrication defect).

metal. The accurate identification of tube deposits is often a necessary part of determining the cause of tube failure.

FIRESIDE TUBE DEPOSITS include soot, slag, corrosion products, and high-temperature oxide.

SOOT is a broad term used to cover all of the ash products (other than slag) that result from combustion. These ash products include carbon, sand, salts such as sodium sulfate, and other materials. Soot deposits are usually powdery or ashy on the tube surfaces near the top of the boiler; but they tend to be packed solid on drums, headers, and the lower ends of the tubes.

SLAG is not a powdery or packed ashlike soot; rather, it is a saltlike material that is fused to the tube surfaces. Slag is objectionable on boiler tubes because it retards the transfer of heat to the tube metal and because it may cause gas channeling, with consequent local overheating of tube metal that is not covered by the slag. Most slags on boiler tubes are soluble enough to be

controlled by periodic washing of firesides. The main way to prevent slag is to avoid burning fuel oil that is contaminated with seawater.

CORROSION DEPOSITS seldom form major fireside deposits. Occasionally, however, bulky deposits of ferrous sulfate may form as the result of the combination of soot and large amounts of water. These deposits have been known to travel away from their original location and adhere to remote rows of generating tubes. The deposits can usually be removed by water washing and mechanical cleaning. The source of the water leakage should be found and corrected. Also, the location of the original deposit should be found, and the area should be carefully inspected for signs of corrosion.

HIGH-TEMPERATURE OXIDE is the term applied to heavy fireside layers of mixed iron oxides formed by overheating of the tube metal. Low water is a frequent cause of high-temperature oxide on the tube firesides. The high-temperature oxide has a rather layered appearance; it resembles

corrosion products and is often wrongly called scale.

Exterior Inspection of Drums and Headers

The exteriors of all boiler drums and headers should be inspected for signs of corrosion under the insulation. Rusty streaks or signs of corrosion on or around the edges of the covering, the drum pads, or the tubes indicate possible corrosion of the drum and should be investigated immediately. If machinery or piping is installed over the boiler, water may drip down on the boiler and work its way under the insulation. In such installations, the boiler drum coverings must be removed, and the exterior of the drum must be inspected carefully.

Inspection of Protection, Seal, and Support Plates

All corrosion-resisting steel plates such as baffle plates, seal plates, superheater support plates, steam drum protection plates, and so forth, must be carefully inspected whenever firesides are opened. These steel plates are subject to damage from overheating, particularly if clogged gas passages interfere with the designed flow of combustion gases and allow extremely hot gases to flow over the plates. Since failure of these parts could have extremely serious consequences, the plates should be inspected at every opportunity and should be renewed when necessary.

Inspection of Uptakes and Smoke Pipes

The uptakes and smoke pipes are examined according to a maintenance system. Check the uptake expansion joints to be sure they are not clogged with soot. Look for ruptures and for loose reinforcing ribs or Z-bar stiffeners. Check the rain gutters to see that they are not plugged with soot. Check the top of the economizer to see if it is clean.

OPERATIONAL INSPECTION AND TESTS

Following the hydrostatic test, the boiler should be fired and brought up to operating pressure and temperature. All automatically and manually operated control devices provided for control of steam and water pressure, hot-water

temperature, combustion, and boiler water level should be inspected and caused to function under operating conditions. All associated valves and piping, pressure- and temperature-indicating devices, metering and recording devices, and all boiler auxiliaries should be inspected under operating conditions. All safety valves and water-pressure relief valves should be made to function from overpressure.

Inspections and tests may be made with the main steam or hot-water distribution valves closed or open as necessary to fire the boiler and operate it under normal operating conditions. Testing the function of automatically or manually controlled devices and apparatus that may interfere with distribution requirements should be one with main steam or hot-water distribution valves closed, as applicable.

The purpose of these inspections and tests is to discover any inefficient operation or maintenance of the boiler or its auxiliaries that may be evidenced under operating conditions. All deficiencies requiring adjustment, repair, or replacement, and all conditions indicating excessive operating costs and maintenance costs should be reported.

Firing Equipment

The operation of all firing equipment, including oil burners, gas burners, fuel injectors, fuel igniters, coal stokers and feeders, and other such equipment provided to introduce fuel into the boiler furnace and ignite the fuel, should be inspected for any deficiency that may be evidenced under operating conditions. In particular, igniters and burners should be checked to ensure that burner protrusion, angle, setting, and so forth, is such that light off and operation are as effective as possible.

Controls

Inspect the operation of combustion controls, steam pressure controls, water temperature controls, and feedwater controls. Assure that the ability of the combustion control and steam pressure control to maintain proper steam pressure (or water temperature in high-temperature water installations) and air-fuel ratio is demonstrated throughout the capacity range of the boiler. Air-fuel ratio should be checked by CO₂ or O₂ measuring devices. On smaller boilers the appearance of the fire may be used as a guide for inspection of air-fuel ratio. Check fully

automatic boiler controls for proper programming sequence and timing with respect to prepurge, ignition, pilot proving, flame proving, and postpurge periods. Check the operation of flame failure and combustion air failure devices to assure that they properly shut off the supply of fuel; do this by simulating a flame failure (manually shutting off the fuel or by other means) and observing the operating of the controls, solenoid valves, and diaphragm-operated valves that are to operate during a flame failure. Inspect feedwater controls and check the ability of the controls to maintain proper water level throughout the range of capacity with first load swings. Check the operation of low-water fuel cutoff and automatic water-feeding devices by draining the float bowl, lowering the boiler water level, or by performing other necessary steps to cause these devices to function, to assure they operate properly. The low-flow cutout on high-temperature water boilers should be tested by reducing the flow until cutout occurs. For additional information on the inspection of the operating conditions of the controls, refer to the section of this RTM that deals with WATER COLUMNS AND GAUGE GLASSES.

Steam and Water Piping

While the boiler is operating, examine all steam and water piping—including connections to the columns—for leaks. If any leaks are found, determine if they are the result of excessive strains caused by expansion and contraction or other causes. Listen for water hammer; if found, determine the cause. Look for undue vibration, particularly in piping connections to the boiler. Where excessive vibration of piping is found, examine connections and parts for crystallization.

Water Columns and Gauge Glasses

With steam on the boiler, blow down the water columns and gauge glasses and observe the action of the water in the glass to determine if the connection to the boiler or the blowoff piping is restricted or not properly free. This will help you determine the true condition of high- and low-water alarms and of the automatic combustion equipment.

Devices

While the boiler is operating, cause the individual mechanisms of LOW-WATER FUEL

CUTOFF and/or WATER-FEEDING DEVICES to operate to assure they function properly.

Where a float-operated, low-water cutoff or water-feeding device or a combination low-water fuel cutoff and water-feeding device is provided, its operation should be tested by opening the drain to the float bowl and draining the bowl to the low-water level of the boiler. When the low-water point is reached, the mechanism of the low-water fuel cutoff should function and shut off the fuel supply to the boiler until boiler water is added to the proper level. Also, at the low-water point, the mechanism controlling the feedwater supply should function to start the feedwater.

Where there is a low-water fuel cutoff device controlled by excess temperature generated in a temperature element located inside the boiler, its operation may be tested by blowing off the boiler to its allowable low-water level. On or before the low-water level is reached, the device should function to shut off the boiler fuel supply until boiler water is added to the proper level.

On high-temperature water boilers, the flow through the boiler should be restricted to the minimum allowed, as shown by the manufacturer's operating data. The point at which fuel cutoff takes place should be noted and adjustments made as required.

With steam on the boiler, observe the STEAM GAUGE pointer for sticking or restriction of its movement. Blow down the pipe leading to the gauge to assure that it is free. Attach an approved test gauge to the pipe nipple provided for this purpose, and compare the accuracy of each steam gauge on the boiler with that of the test gauge. When inaccuracy of any gauge is evidenced or suspected, it should be removed and calibrated by means of a deadweight gauge tester or other device designed for this purpose. When several boilers are in service and connected to a common steam main, compare the readings of the separate gauges. All TEMPERATURE-INDICATING DEVICES should be observed for indications of excessive temperature, particularly during and immediately after the time high-load demands are made on the boiler. While the boiler is operating under normal conditions, observe the operation of all METERING AND RECORDING DEVICES. When there is evidence that any such device is not functioning properly, it should be adjusted, repaired, or replaced as necessary.

Blowoff Valves

Test the freedom of each blowoff valve and its connections by opening the valve and blowing off the boiler for a few seconds. Determine if the valve is excessively worn or otherwise defective, and if there is evidence of restrictions in the valve or connected piping preventing proper blowoff of the boiler.

Stop and Check Valves

While the boiler is operating, inspect the operating condition of each stop and check valve where possible. Serious defects of externally controlled stop valves may be detected by operating the valve when it is under pressure. Similarly, defects in check valves may be detected by listening to the operation of the valve or observing any excessive vibration of the valve as it operates under pressure.

Pressure-Reducing Valves

While there is pressure on the system, open and then close the bypass valve as safety and operating conditions permit. Also, observe the fluctuation of the pressure gauge pointer as an aid in determining possible defects in the operation of the pressure-reducing valve or the pressure gauge. Look for any evidence that may indicate improper condition of the relief or safety valves provided for the pressure-reducing valves.

Boiler Safety and Water-Pressure Relief Valves

Test the blowoff setting of each safety valve for steam boilers and each water-pressure relief valve for hot-water boilers by raising the boiler pressure slowly to the blowoff point. In turn, test the releasing pressure of each valve, gagging all other safety or relief valves except the one being tested. Observe the operation of each valve as blowoff pressure is reached. Compare the blowoff setting with setting requirements specified in paragraph 1 or 2 of this section, as applicable, and make adjustments where necessary. When the steam discharge capacity of a safety valve is questionable, it should be tested by one of the methods given in paragraph 3 of this section. When the pressure-relieving capacity of a pressure-relief valve is questionable, it should

be tested according to the procedures given in paragraph 4 of this section.

1. **SAFETY VALVES—SETTING REQUIREMENTS.** Note this word of caution: Before adjusting safety valves on electric steam generators, be sure that the electric power circuit to the generator is open. The generator may be under steam pressure, but the power line should be open while the necessary adjustments are being made. At least one safety valve should be set to release at no more than the maximum allowable working pressure of the steam boiler. Safety valves are factory set and sealed. When a safety valve requires adjustment, the seal should be broken, adjustments made, and the valve resealed by qualified personnel only. When more than one safety valve is provided, the remaining valve or valves may be set within a range of 3% above the maximum allowable working pressure. However, the range of the setting of all the safety valves on the boiler should not exceed 10% of the highest pressure to which any valve is set. Each safety valve should reseal tightly with a blowdown of not more than 2 psig or 4% of the valve setting, whichever is greater.

In those cases where the boiler is supplied with feedwater directly from the pressure main without the use of feeding apparatus (not including return traps), no safety valve should be set at a pressure greater than 94% of the lowest pressure obtained in the supply main feeding the boiler.

2. **PRESSURE-RELIEF VALVE—SETTING REQUIREMENTS.** At least one pressure-relief valve should be set to release at not more than the maximum allowable working pressure of the hot-water boiler. When more than one relief valve is provided on either hot-water heating or hot-water supply boilers, the additional valve (or valves) may be set within a range not to exceed 20% of the lowest pressure to which any valve is set. Each pressure-relief valve should reseal tightly with a blowdown of not more than 25% of the valve setting.

3. **SAFETY VALVE—CAPACITY TEST.** When the relieving capacity of any safety valve for steam boilers is questioned, it may be tested by one of the three following methods:

a. By the accumulation test, which consists of shutting off all other steam-discharge outlets from the boiler and forcing the fires to the maximum. The safety valve capacity should be sufficient to prevent a pressure in excess of 6% above the maximum allowable working pressure.

This method should not be used on a boiler with a superheater or reheater.

b. By measuring the maximum amount of fuel that can be burned and computing the corresponding evaporative capacity (steam-generating capacity) upon the basis of the heating value of this fuel. These computations should be made as outlined in the code.

c. By determining the maximum evaporative capacity by measuring the feedwater.

When either of the methods outlined in (b) or (c) above is employed, the sum of the safety valve capacity should be equal to, or greater than, the maximum evaporative capacity (maximum steam-generating capacity) of the boiler.

If you discover that the relieving capacity is inadequate because of deficiencies in the valve, the valve should be repaired or replaced. If the relieving capacity of the valve is found to be satisfactory within the proper relieving range of the valve but inefficient for the steam-generating capacity of the boiler, additional safety valve capacity should be provided.

4. **PRESSURE-RELIEF VALVE—CAPACITY TEST.** When the relieving capacity of any pressure-relief valve for hot-water boilers is questioned, the capacity can be tested by turning the adjustment screw until the pressure-relief valve is adjusted to the fully open position. The pressure should not rise excessively. When the test is completed, reset the pressure-relief valve to the required setting. This test is made with all water discharge openings closed except the pressure-relief valve being tested. When the discharge is led through a pipe, determine at the time the valve is operating if the drain opening in the discharge pipe is not properly free, or if there is evidence of obstruction elsewhere inside the pipe. If deemed necessary to determine the freedom of discharge from the valve, the discharge connection should be removed. After completing tests and adjustments, the inspector should seal the safety adjustment to prevent tampering.

Boiler Auxiliaries

While the boiler is operating under normal conditions, observe the operation of all boiler auxiliaries for any defects that may prevent proper functioning of the boiler or indicate a lack of proper maintenance of auxiliary equipment. The unnecessary use of multiple auxiliaries or the use of a large auxiliary during a light-load period (when a smaller auxiliary could be substituted)

should be discouraged. The maximum use of steam-driven auxiliaries short of atmospheric exhaust should be encouraged. Steam leaks, wastage to atmosphere, and so forth, should be called to the attention of operating personnel. Particular attention should be given to deaerator venting practice. Venting should be held to the minimum required to preclude oxygen entrainment in the feedwater.

When intermittently operating condensate pumps are used, look for any tendency toward creation of a vacuum when a pump starts. If this happens, recommend installation of a small, continuously operating, float-throttled, condensate pump (in parallel with intermittently operating pumps) to assure a condensate flow at all times. If there are a number of intermittently operating condensate pumps, it may be possible to convert one of them (if of small enough capacity) to continuous throttled operation.

PLANT OPERATION

To operate boilers or be a plant supervisor, you need to know all the mechanical details of the boiler you are operating and its associated auxiliaries. However, just knowing this information is not enough. To be a professional boiler operator or plant supervisor, you must develop a keen eye for trouble, a finely tuned ear, and an overall sense of awareness concerning boiler plant operation at all times.

As an operator and/or supervisor of a boiler plant, you must learn to tell the difference between normal and abnormal operating conditions. By training yourself to notice and analyze strange noises, unusual vibrations, abnormal temperatures and pressures, and other indications of trouble, you will be better able to prevent any impending trouble or casualty to the plant.

OPERATORS

Boiler plant operators must maintain accurate records. Logs provide a means of recording continuous data on boiler plant performance and analysis of operation. Logs are arranged for use over a 24-hour period, consisting of three 8-hour shifts. Log entries should be carefully made in columns.

Logs

Information of importance in the operation of boilers must be recorded. This section provides information concerning the type of data that should be recorded in logs.

1. Steam pressures. Steam pressure is recorded by the operator from steam gauges and shows performance of automatic or manual control.

2. Steam flow. Actual output of the plant is recorded by the operator in pounds per hour to obtain steam flow. This record determines the number of boilers to operate for greatest efficiency.

3. Feedwater heater. Feedwater-heater pressure indicates whether proper deaerating temperature can be maintained in the heater. Feedwater-heater temperature shows the effectiveness of the feedwater heater. A drop in steam supply pressure or insufficient venting may cause low heater temperature.

4. Feed-pump pressure. Feed-pump pressure indicates effectiveness of the boiler feed pumps. If feedwater supply fails, the pressure reading enables the operator to determine whether or not the difficulty is in the feed pumps. The pumps are defective when the feed-pump pressure reading is below normal.

5. Forced draft. Forced draft is an indication of thickness of the fuel bed. The most satisfactory value varies with different installations and fuels and is determined by actual trial.

6. Furnace draft. Furnace draft, when used in connection with forced draft, should be slightly less than atmospheric pressure to prevent smoke from leaking into the boiler room and overheating the furnace lining. If only an induced or natural draft is used, furnace draft must be sufficient to cause the quantity of air required for combustion to flow into the furnace. Operating with a furnace draft higher than actually required results in excessive air leakage into the setting with an accompanying loss in efficiency.

7. Last-pass draft. Last-pass draft shows actual draft produced by a stack or an induced-draft fan. Fireman should become familiar with last-pass draft at various ratings when the boiler is operating satisfactorily. A decrease in last-pass draft with other conditions constant indicates leaking baffles. An increase in last-pass draft shows that gas passes are becoming clogged.

8. Percent CO₂ flue gas. Percent CO₂ flue gas is a measure of relative quantities of air

supplied with fuel. It is kept at a value that has been established as most satisfactory for the plant, fuel, rating, and like factors. In plants not equipped with CO₂ recording meters, this value is determined with a hand gas analyzer. With experience, you can determine the correct amount of air supplied for a furnace by checking the draft gauges and from personal observation. In all cases, you should check values by use of a hand gas analyzer.

9. Flue-gas temperature. Flue-gas temperature is an indication of the portion of heat leaving the boiler with the flue gases. This heat represents a direct energy loss in fuel. Abnormally high flue-gas temperatures at a given boiler rating are caused by dirty heating surfaces or leakage of baffles. If the heating surface has a coating of soot and ash, heat that cannot escape is discharged to the stack. Leakage through baffles allows the gases to take a shorter path than intended and reduces contact of gases with the entire heating surface. Excessive fouling of the boiler's firesides increases the draft loss while leaking baffles decreases the draft loss. Either condition raises the temperature of flue gases above normal.

10. Fuel. Always determine the quality of fuel being used as this represents a major operating cost.

a. Pounds of coal. Procedures for determining the quantity of coal burned depends upon the means available. You may use scales that automatically dump weighed quantities of coal into the stoker or pulverizer hoppers. A register indicates the number of "dumps" that, multiplied by the weight of coal discharged per dump, gives the total. Another weighing method uses traveling ladders equipped with scales so that the weight of each load can be recorded before it is dumped into the boiler hopper. In the absence of a weighing device, the quantity of coal consumed can be determined by filling and leveling bunkers at given intervals and recording the coal used from the report of coal received during a given interval. Methods for approximating coal burned by counting stoker revolutions are only estimates and are subject to considerable error when the size of coal changes.

b. Cubic feet of gas. The quantity of gas used is indicated on a meter. The readings can be direct or they may necessitate calculation by use of a meter factor.

c. Gallons of oil. Fuel oil quantities are determined by use of a measuring stick. Tables supplied with a given tank are then used to determine quantity from level of fuel. Tanks may also be supplied with gauges that can be read directly.

11. Outside temperature. A heating plant load is greatly influenced by outside temperature. Record this temperature for comparison with steam generated and fuel used. These comparative values are useful in determining abnormal fuel consumption and in estimating future requirements.

12. Makeup water. The quantity of makeup water used should be recorded. This enables the operator to note an abnormal increase in makeup water before a dangerous condition develops. Return all possible condensate to the boiler plant; this will save on water and chemicals being used to treat the water.

13. Water Pressure. Feedwater is most important to the safe operation of the boiler plant. The hot-water supply temperature should be recorded. Insufficiently heated water can cause scaling or deposits in a boiler.

14. Hot-water supply temperature. Record the hot-water supply temperature. Insufficiently heated water can cause scaling or deposits in a boiler.

15. Water softeners. Where softeners are employed, you should keep a meter record to inform the shift operator of the time when the units must be regenerated. A decrease in the time of runs between regeneration is an indicator of either an increase in hardness of incoming water or of deterioration of the softening material. The note columns are for recording total water softened and pounds of salt added.

16. Totals and averages. Space is provided for recording total and average quantities per shift.

17. Steam flow. To find the quantity of steam generated, subtract the steam flowmeter integrator reading at the start of shift from the reading at the end of the shift, then multiply the remainder by the meter constant. Dividing steam generated by fuel burned (pounds of coal, cubic feet of gas, or gallons of oil) yields a quantity that indicates the overall economy obtained. If the plant does not have a steam flowmeter, pumps can be calibrated for flow and a record kept of their operating time, or the condensate and makeup water can be metered.

18. Boiler feed pump in service. A record of the boiler feed pump in service makes it possible to determine appropriate operating hours and to see that the various pumps are used for equal lengths of service.

19. Soot blown time and blowdown. A record of blown time and blowdown is valuable to the relieving shift operator because it is an indicator

of plant conditions, and it will show irregularities if any exist.

20. Phosphate, caustic soda, and tannin added. A record of phosphate, caustic soda, and tannin used is valuable in keeping correct boiler water analysis and in determining the total amount of chemicals used.

21. Remarks. The remarks column is in the upper right area of the log sheet. List all the equipment that is to be checked each day according to the schedule listed in TM 5-651. Annotate all the irregularities that are found in connection with these inspections. List the dates when the boilers are drained and washed and at other intervals, as determined by local water conditions. Indicate the degree of internal cleanliness.

22. Using personnel. Names of personnel responsible for these data must be entered in the appropriate area on the bottom of the log sheet.

Turnover/Watch Relief

When an operator comes on duty, he should make an operational inspection to ensure that everything is operating normally. The points to be checked are as follows:

1. Check the water level in the gauge glass on each boiler by opening and closing the try cocks.

2. Check the low-water cutoffs and the boiler feed equipment by blowing down the water columns on each boiler.

3. Check the steam pressure and compare it with the steam pressure that the plant should deliver.

4. Check the boilers for leaks or other conditions that can affect plant operation.

5. Check for proper operation of the boiler room accessories.

6. Check the fuel supply and the firing equipment.

7. Check the condition of the fires to determine if they are clean.

8. Check the general appearance of the boiler room, fixtures, piping, and insulation.

9. Check the boiler room record sheets to determine if any troubles were encountered by the previous shift operator.

10. Question the operator being relieved about plant operation and the troubles encountered.

11. Check for any verbal or written orders with which you are to comply.

Table 12-2.—Effects of Inadequate or Improper Water Conditioning

EFFECT	CONSTITUENT	REMARKS
Scale	Silica	Forms a hard, glassy coating on internal surfaces of boiler. Vaporizes in high-pressure boilers and deposits on turbine blades.
	Hardness	CaSO ₄ , MgSO ₃ , CaCO ₃ and MgCO ₃ form scale on boiler tubes.
Corrosion.	Oxygen	Causes pitting of metal in boilers, and steam and condensate piping.
	Carbon dioxide	Major causes of deterioration of condensate return lines.
	O ₂ - CO ₂	Combination is more corrosive than either by itself.
Carryover.	High boiler water concentrations.	Causes foaming and priming of boiler and carryover in steam, resulting in deposits on turbine blades and valve seats.
Caustic embrittlement.	High caustic concentration.	Causes intercrystalline cracking of boiler metal.
Economic losses.	Repair of boilers.	Repair pitted boilers and clean heavily scaled boilers.
	Outages	Reduce efficiency and capacity of plant.
	Reduced heat transfer.	High fuel bills.

PLANT SUPERVISOR

As a boiler plant supervisor, you are expected to organize and manage the overall operation of the boiler. Ensuring that daily logs are maintained by operators, submitting monthly operation reports and logs, checking maintenance requirements, training personnel, and so forth, are included in your duties and responsibilities. Each boiler plant has its unique requirements. Only through operating your specific plant and completely familiarizing yourself with it can you establish a comprehensive management program.

This chapter cannot cover all the aspects of supervising a boiler plant. You must refer to current Navy publications and manufacturer's

manuals that pertain to your specific plant. When assigned as a boiler plant supervisor, establish an on-site library of these publications and manuals, and keep them handy for immediate reference.

WATER CHEMISTRY

The effects of inadequate or improper water conditioning can cause major problems in the operation of boilers. Manufacturer's specifications must be strictly adhered to. Table 12-2 outlines the effects and results of poor water treatment of boiler water. By establishing an aggressive water-treatment program, you can greatly reduce inefficient boiler operation and high maintenance costs.

Utilitiesman 3 & 2, volume 2, chapter 14, NAVEDTRA 10661, discussed at length the boiler water tests normally encountered in the field. You should review this information. This section discusses how to treat boiler water, based on the results of those tests.

CHEMICAL MAKEUP OF WATER

Water has been termed the *universal solvent*. Water has a tendency to dissolve nearly everything that comes in contact with it. The purer the water is, that is, the lower its dissolved solids content, the greater the tendency to dissolve its surroundings. Pure water, if stored in a stainless steel tank, after a short contact time, has a very small amount of iron, chromium, and nickel from the tank dissolved in it. This dissolving of the tank does not continue indefinitely with the same water. The water, in a sense, has satisfied its appetite in a short time and does not dissolve any more metal. Pure water, if exposed to air, immediately absorbs air and has oxygen, from the air, dissolved in it. A glass of tap water at 68°F will contain 9.0 ppm of oxygen. If the tap water is heated to 77°F, some of the oxygen is driven out and the water contains 8.2 ppm of oxygen. The higher the temperature of the water, the less dissolved oxygen it can hold. Conversely, the higher the pressure imposed on the water, the greater the dissolved oxygen that the water can hold. Water, when boiled, produces steam. The steam contains some of the liquid water. There is never a perfect separation of pure steam from the boiling water. The steam above the boiling water will always have entrained with it some of the boiling water. The foregoing three ideas, water is a universal solvent, water dissolves oxygen when in contact with air, and boiling water is always entrained with steam, should assist you in understanding the nature of feedwater.

The feedwater, as it enters the boiler steam drum, is now considered boiler water. Complete understanding of the nature of boiler water can be gained by temporarily making the assumption that no water treatment, chemical addition, or blowdown is applied to the boiler water. The character of the boiler water continuously changes as the boiler steams. The dissolved and suspended solids, contained in the feedwater, concentrate in the boiler water at the rate of eight-fold every hour if the boiler is producing steam at 50% of its normal capacity. Three damaging conditions arise in the boiler as the boiler water continues to steam without any treatment. *Scale formation* on the steam generating surfaces, *corrosion* of the boiler

metal, and boiler water *carryover* with the steam due to foaming are the three results of untreated boiler water.

To prevent scale formation on the internal water-contacted surfaces of a boiler and to prevent destruction of the boiler metal by corrosion, feedwater and boiler water must be chemically treated. This chemical treatment prolongs the useful life of the boiler and results in appreciable savings in fuel, since maximum heat transfer is possible when no scale deposits occur.

CHEMICAL TREATMENT (EXTERNAL AND INTERNAL)

The method of using chemicals may take the form of external treatment, internal treatment, or a combination of both. The principal difference between these forms of treatment is that in external treatment the raw water is changed or adjusted by chemical treatment outside of the boiler so that a different type of feedwater is formed, while in internal treatment the water is treated inside the boiler by feeding chemicals into the boiler water, usually through the feed lines. Again, in external treatment the main chemical action takes place outside the boiler, while in internal treatment the chemical action takes place within the boiler.

INTERNAL TREATMENT AND PREVENTION

At many Navy installations, the boilers are not large and do not operate at high pressure. When the makeup water is not too high in hardness or dissolved solids, it permits good operation with only internal treatment. Under this condition, the installation of external treating equipment is not necessary. Chemical treatment covered in this chapter applies primarily to internal treatment.

Scale

When water evaporates in a boiler, the hard components that were in the water, such as calcium salts, magnesium salts, and other insoluble materials, form deposits on the tubes and other internal surfaces. These deposits are known as scales. Actually, the temperature of the water determines how well the different salts dissolve and how long they remain dissolved. Some salts are such that the hotter the water, the better they stay dissolved. Other salts stay dissolved while the water is at a relatively low temperature but form

Table 12-3.—Chemicals Used by NAVFAC for Internal Boiler Water Treatment in Shore-Based Boilers

CHEMICAL	PURPOSE	COMMENT
Sodium hydroxide NaOH (caustic soda).	Increase alkalinity, raise pH, precipitate calcium sulfate as the carbonate.	Contains no carbonate, therefore doesn't promote CO ₂ formation in steam.
Sodium carbonate Na ₂ CO ₃ (Soda ash)	Increase alkalinity, raise pH, precipitate magnesium.	Lower cost, more easily handled than caustic soda. But some carbonate breaks down to release CO ₂ with steam.
Sodium phosphates NaH ₂ PO ₄ , NaHPO ₄ , Na ₃ PO ₄ , NaPO ₃ .	Precipitate calcium as hydroxyapatite (Ca ₁₀ (OH) ₂ (PO ₄) ₆).	Alkalinity and resulting pH must be kept high enough for this reaction to take place (pH usually above 10.8).
Sodium aluminate NaAl ₂ O ₄ .	Precipitate calcium, magnesium	Forms a flocculent sludge.
Sodium sulfite Na ₂ SO ₃	Prevent oxygen corrosion.	Used to neutralize residual oxygen by forming sodium sulfate. At high temperatures and pressures, excess may form H ₂ S in steam.
Hydrazine hydrate N ₂ H ₄ ·H ₂ O (35%).	Prevent oxygen corrosion.	Remove residual oxygen to form nitrogen and water. One part of oxygen reacts with three parts of hydrazine (35% solution).
Filming amines; Octadecylamine, etc.	Control return-line corrosion by forming a protective film on the metal surfaces.	Protects against both oxygen and carbon dioxide attack. Small amounts of continuous feed will maintain the film. Do not use where steam contacts foods.
Neutral amines; morpholine, cyclohexylamine, benzylamine.	Control return-line corrosion by neutralizing CO ₂ and adjusting pH of condensate.	About 2 ppm of amine is needed for each ppm of carbon dioxide in steam. Keep pH in range of 7.0 to 7.4 or higher.
Sodium nitrate NaNO ₃	Inhibit caustic embrittlement	Used where the water may have embrittling characteristics.
Tannins, starches, glucose and lignin derivatives.	Prevent feed line deposits coat scale crystals to produce fluid sludge that won't adhere as readily to boiler heating surfaces.	These organics, often called protective colloids, are used with soda ash, phosphate. Also distort scale crystal growth, help inhibit caustic embrittlement.

Table 12-3.—Chemicals Used by NAVFAC for Internal Boiler Water Treatment in Shore-Based Boilers—Continued

CHEMICAL	PURPOSE	COMMENT
Seaweed derivatives; (Sodium alginate, Sodium mannuronate).	Provide a more fluid sludge and minimize carryover.	Organics often classed as reactive colloids since they react with calcium and magnesium and absorb scale crystals.
Antifoams; (polyamides, etc.).	Reduce foaming tendency of highly concentrated boiler water.	Usually added with other chemicals for scale control and sludge dispersion.
Proprietary compounds (of ball or brick type).	Do not use for water treatment	Boilers 125 psig and above, all power plant boilers, all boilers using intermittent blowdown.
	May be used for water treatment	Low makeup boilers (under 125 psig) for space heating. High makeup boilers (under 125 psig) with continuous blowdown and stable feedwater, if cost saving is effected.

solid crystals (scales) that come out in increasing amounts as the water gets closer to becoming steam.

The scale-forming salts stay dissolved in the water and in the cooler parts of the boiler, but when the water reaches the hot tubes, these salts start forming solid particles that come out of the water and stick to the hot metal parts as scale deposits. These deposits are highly objectionable because they are poor conductors of heat, actually reduce efficiency, and are frequently responsible for tube failures. Some of the principal scale-forming salts to be considered in most cases are listed as follows:

Calcium sulfate	CaSO_4
Calcium silicate	CaSiO_3
Magnesium silicate	MgSiO_3
Calcium hydroxide	Ca(OH)_2
Calcium carbonate	CaCO_3
Magnesium hydroxide	Mg(OH)_2

Scale is made up of three main parts: calcium sulfate, calcium carbonate, and silicates of calcium and magnesium. Scales that are principally calcium sulfate or chiefly of the aforementioned silicates are very hard; those scales that are principally calcium carbonate with little silicate

are somewhat softer. A scale consisting chiefly of calcium carbonate may appear only as a thin, porous, soft scale that does not build up in thickness.

Scale can be prevented by the intelligent use of proper water treatment, and that is one of the objectives of the boiler water test and treatment program.

Prevention and Treatment for Scale Control

Scale-forming substances cannot always be prevented from entering the boiler, but they can be made to form a fluid sludge. The problem then is simply one of proper chemical treatment and blowdown.

The selection of chemicals for internal treatment is determined by many factors: the kind of feedwater hardness (whether carbonate or sulfate); the ability of feedwater to build up required causticity; the type of external treatment, if used; the pH and percentage of condensate returns; the location of chemical feed injection; and the cost and availability of chemicals.

The first two chemicals to be considered for boiler water treatment of shore-based boilers are caustic soda and sodium phosphate (table 12-3).

The caustic soda prepares the way by making the water definitely alkaline (high pH). The sodium phosphate can then attack the calcium magnesium and silica salts and convert them into a fluid sludge that can be removed by blowdown.

Caustic soda is used when the feedwater cannot build up the required causticity residual in the boiler water. Use of soda ash (Na_2CO_3) is not authorized in steaming boilers because it breaks down under heat to form undesired carbon dioxide (CO_2). This gas is corrosive to condensate return lines. The Navy boiler compound customarily used aboard ship is not authorized because it contains about 39% soda ash.

Sodium phosphate (NaPO_4) has a special affinity (attraction) for calcium, and in boiler water the phosphate joins with calcium to precipitate calcium phosphate (CaPO_4).

Phosphate prevents the formation of calcium scales, such as calcium sulfate, calcium carbonate, or calcium silicate. The precipitate of calcium phosphate develops as a finely divided fluid material that can readily be removed by blowdown. The sodium phosphate dosage should be regulated to maintain a residual reading of 30 ppm to 60 ppm.

Sludge

Another source of tube coating is BAKED SLUDGE. This sludge comes from dirt, oil, water-treatment chemicals, and so forth, that are suspended in dirty feedwater. The solids settle on tube surfaces and absorb the heat intended to be transferred to the water. The heat then cooks the sludge into a hard coating on the tube walls. These deposits are as hard or harder to remove than TRUE SCALE and should be recognized as a completely different problem. Methods of preventing and combating baked sludge are different from methods of preventing and combating scale.

Baked sludge is very hard to remove by mechanical means, and boiler compound has no effect on it at all. The best method found to combat sludge is to know where it comes from, make it gather by proper treatment, and blow it out before it cooks.

Prevention and Treatment for Sludge Control

When the proper causticity residual is maintained and phosphate is fed in correct amounts, the scale-forming impurities in boiler water

sludges out and should be easy to blow out. Sometimes, however, the characteristics of the precipitated chemicals are such that the sludge formed does not go along with the water and leave the boiler with the blowdown. It has been discovered that additives called sludge conditioners cause the sludge to flow better. Most sludge conditioners are organic substances that act as dispersants. They keep the sludge in a fluid state by holding the precipitates as finely divided particles. As the precipitated chemicals settle, a loose fluid mass that is easy to blow out is formed. The only sludge dispersant approved by NAVFAC for use in shore-based boilers is QUEBRACHO TANNIN.

Generally, when quebracho tannin is used, sufficient quantities are fed to the boiler to give the boiler water a medium tea color. If the causticity residual is high, a darker color should be maintained. This darker color for high causticity aids in preventing hardening of metal in the boiler. As the tannin particles become part of the sludge and are blown out, the brown color, given to the water by the initial dose of tannin, becomes a lighter color, and more tannin must be added.

Proper blowdown is important because some sludges are almost always in the boiler water. When only parts of the boiler are badly sludged, blowdown may not be complete or there are areas of poor circulation. The boiler design may be such that even good blowdown does not clear all the parts. Another concern is that frequency, time, and the kind of blowdown being used may not be complete or correct to maintain optimum conditions.

A small amount of seawater in the feedwater causes heavy sludging. Where seawater is likely to contaminate feedwater or where evaporated seawater is used for feedwater, every precaution should be taken to prevent saltwater contamination of the feedwater. Regular daily boiler water tests will show up contaminated feedwater so that it can be corrected before serious harm is done.

Where makeup water is clean and not much sludge shows at bottom blowdown, tannin may not be necessary. Where there is a lot of sludge, the addition of tannin is a big help in keeping the boiler free and clean. Also, much less sludge-forming materials are required when the raw water makeup is upgraded by external treatment.

Corrosion

Corrosion is the deterioration of metal by chemical action. When dissolved oxygen is present in the boiler water, corrosion begins and continues until all metal has been transformed into iron oxide or, commonly stated, rust. When rust forms in the boiler, it may drop out as sludge or cling to other metal surfaces. It is not economically possible to prevent at least some of the iron in the boiler from going into solution. All iron not protected by a coating or film of something that keeps out moisture and air is sooner or later going to become RUST. The idea is to slow down the process as much as possible by KEEPING OXYGEN OUT and by maintaining a proper causticity residual.

The pH level of boiler water is also a factor in corrosion. The active agent in the corrosion of the internal water surface of boilers is oxygen; however, the combined action of oxygen and the acid action of the water are required for the corrosion process. To suppress the acid action of the water, you can raise the pH value of the water by adding caustic soda. The lower the pH value, the stronger the acid concentration. The higher the pH value, the weaker the concentration. Economically, acid corrosion cannot be stopped completely, but it can be suppressed by keeping oxygen out of the boiler and by maintaining a proper pH value and causticity range.

Prevention and Treatment for Oxygen Corrosion

The chemical most commonly used in oxygen removal is sodium sulfite, and it is quite often referred to as an oxygen scavenger. It is an example of a chemical that actually reacts with the harmful constituent. It reacts with oxygen, forming a neutral compound—sodium sulfate.

When enough sodium sulfite is fed into a boiler so that a surplus of the chemical is maintained, any of the oxygen getting into the boiler water is taken up by the chemical, and the boiler water is kept virtually free of oxygen. By maintaining a suitable residual, little, if any, corrosion due to oxygen occurs. Common practice in feeding sodium sulfite is to maintain a surplus residual of about 20 ppm to 50 ppm in the boiler water. This is generally enough sodium sulfite to react with normal amounts of oxygen that might get into the boiler. Higher concentrations of sodium sulfite are unnecessary.

Sodium sulfite dissolves readily in water and must be fed at a point between the feed heater and the boiler so that it is used to take up only the oxygen that gets by the deaerator or heater. If the sodium sulfite is fed through the feed lines by continuous feeding, it is always present in the feed lines and takes up oxygen in the feedwater in addition to maintaining a surplus in the boilers.

Another advantage of using sodium sulfite is that if, for any reason, a feedwater heater or deaerator becomes inoperative or efficient operation is temporarily interrupted, the sodium sulfite residual present in the boiler water can take up the larger amounts of the oxygen getting in. At the same time, the concentration of sodium sulfite drops. This is shown by test analysis of the boiler feedwater. This test gives the operator ample warning of an existing malfunction within the boiler feedwater supply system. Immediate steps should be taken to correct this off-standard condition. Feedwater or makeup water tanks should be heated to a temperature of 180°F to 200°F. This heat alone helps to dispense of most of the dissolved oxygen before it can enter the boiler. It also allows for more economical use of sodium sulfite.

The prevention of corrosion in the boiler means regulating the alkalinity of the water, producing protective films, and removing dissolved oxygen. These preventive measures are accomplished by maintaining the proper chemical residuals in the boiler water and by proper deaeration.

Carryover—Foaming and Priming

The word *priming* is used rather loosely to express the action of the water and steam in a boiler when an unusual amount of water is being carried over with the steam. For a given boiler installation, a certain amount of water or moisture in the steam is tolerated. The amount depends upon the use of the steam, the boiler construction, and the facilities for removing the water from the steam. The mechanical causes include deficiency in boiler design, high water level, improper method of firing, overloading, and sudden load changes. A poorly designed boiler may have insufficient steam disengaging space. It is fairly obvious that the faster the steam is produced in a given vessel, such as a boiler, the more violent is the boiling effect. But when the steam space above the water level is large enough, the steam leaving the boiler does not show any evidence of carryover. The size of the steam

header and the velocity of steam leaving the boiler are, therefore, important elements in boiler design. As the rate of steam production goes up, so does the tendency for steam contamination. The sudden opening of a steam valve or the cutting in of a boiler too quickly speeds up the production of steam, which can cause violent bubbling and carryover.

The primary chemical causes of carryover are high concentrations of totally dissolved and suspended solids in the boiler water, excessive alkalinity, and the presence of oil.

Foaming is the production of froth or unbroken bubbles on the surface of the boiler water. The froth may be thin, with few bubbles overlying each other, or it may build up throughout the steam space. Under such conditions it is difficult to free the steam of the liquid films, and the moisture content increases. When certain substances are dissolved in water, they concentrate somewhat more in the body of the liquid than on the surface; others concentrate more on the surface than in the body. In either case, the surface tension of the water is affected, and bubble film develops. The formation of froth depends upon the tenacity of the films of liquid that form the shells of the bubbles. A tough film can develop that refuses to break and release the steam. Apparently, finely divided solids in suspension increase the stability of the film so that the combination of salts in solution and finely divided solids cause foaming to develop more readily than when either one is present by itself. Soaps getting into the boiler from outside sources or formed within the boiler from oils or animal greases intensify the foaming action. Water can be carried over in the steam without formation of froth. When a pure water that does not foam is boiled, it frequently "bumps" as unstable steam bubbles are formed. These rapidly reach the surface of the water and instantaneously burst through. Parts of the water tend to become superheated and suddenly turn to steam. Fine solid particles released in water under these conditions cause the immediate production of much steam. This may occur in a boiler when particles of scale suddenly become loose.

When a boiler is foaming or priming, it is difficult and quite often impossible to read the true level of the boiler water on the gauge glass. The slugs of boiler water can wreck turbines or engines. The carryover of boiler water solids, usually caused by foaming and priming, disrupts operation of the equipment coming in contact with the steam. Deposits form in steam piping,

valves, superheaters, engines, or turbines. These solids erode the turbine blades and frequently create out-of-balance conditions to the rotor. They often clog tubing, a pipe, and other apparatus following the boiler. When live steam is used for processing purposes or for cooking, the solids can seriously damage the final product. Remember also, any moisture carryover with the steam is an additional heat loss through the steam line.

Prevention and Treatment for Carryover—Foaming and Priming

There are two kinds of solids present in most boiler water—the dissolved solids, or substances that are in solution, and suspended solids. Suspended solids are finely divided solid particles floating around in the water. This is material left over after the scale-forming and corrosive salts have been changed into sludge by chemical treatment.

When a boiler is steaming, the feedwater continuously carries dissolved mineral matter into the boiler. However, the steam leaving the boiler carries very little mineral matter with it. The concentration of dissolved solids in the boiler water, therefore, keeps building up unless properly controlled by continuous or intermittent blowdown.

In water tube boilers, concentrations are generally highest at the place where the mixture of steam and water from the tubes spills over into the steam drum. Where total concentrations are not reduced sufficiently by the bottom blow, another blowdown line should be installed to remove water from the drum at the point where TDS (total dissolved solids) concentrations are the highest. This blowdown is generally operated continuously when the boiler is in service and is called a continuous blowdown.

The best remedy for foaming and priming carryover is the proper blowdown of TDS. The continuous blowdown should be regulated to maintain the TDS at 3,000 to 4,000 ppm. The greater the TDS that can be carried without trouble, the less water, fuel, and chemicals required or wasted in the TDS blowdown.

CHEMICAL TREATMENT DETERMINATION

Because raw water conditions vary so greatly with locale, it is impossible to recommend a single, specific water treatment. Whenever possible, a

water treatment chemist should be consulted, and his or her recommendations for the chemical treatment of boiler water should be followed. The degree of success of any water treatment program depends upon how well the recommendations for treatment are monitored.

When the services of a qualified water treatment chemist are obtained, his or her recommendations should include the following:

- The treatment formula
- The treatment ingredients
- Instructions to the boiler operator in the use of the treatment
- Periodic visits to the plant to check on the results of the treatment plan

When the operator follows instructions and uses proper blowdown procedure, scale and sludge in the boiler are reduced to a minimum. Blowdown limits the amount of dissolved and suspended solids in the boiler water.

Consulting a chemist is an ideal situation. SEABEES seldom operate under ideal situations, especially during contingency operations. How do you determine the initial chemical treatment for a boiler, and, then, how do you establish an effective treatment program? Some general guidelines follow.

The first determination you will have to make is the steaming rate of the boiler, expressed in pounds per hour. This is a fairly simple computation. You first determine the boiler horsepower (BHP); then multiply the result by 34.5 pounds. For example, if you have a 100-horsepower boiler operating at one-half fire, your steaming rate would be 1,725 pounds of steam per hour.

$$1 \text{ BHP} = 34.5 \text{ lb steam/hour}$$

$$100 \times 34.5 = 3,450 \text{ lb steam/hour at high fire}$$

$$3,450 \div 1/2 = 1,725 \text{ lb steam/hour at one-half fire}$$

To determine the initial chemical dosage, you must know the hardness of the raw water. A chemist can tell you this; however, in the field you must determine it by experimentation. The harder the water, the more phosphates you must add during treatment to obtain correct phosphate residuals. The example that follows assumes zero

hardness of the raw water and uses a 1,725-pound steaming rate.

1. Mix the following chemicals in 28 gallons of water:

- a. 1 1/4 lb of sodium sulfate
- b. 1/2 lb of trisodium phosphate
- c. 1/2 lb of caustic soda

2. Adjust the chemical feed rate to 3 gallons per hour (allows for 8 to 10 hours of steaming).

The chemical dosage varies with the steaming rate of the boiler. To establish your water-treatment program, use the following steps every hour of operation for the duration of your initial chemical batch.

1. Determine the hourly steaming rate
2. Test for phosphate residual (30-60 ppm)
3. Test for sulfite residual (25-50 ppm)
4. Test for pH (9.5 to 11.5)
5. Test for TDS (3,000 to 4,000 ppm)

You should make a log entry of these test results every hour. This establishes a history of the tests with accompanying results. At the completion of the initial chemical dosage, you can either add or subtract chemicals, based on your log. It may take several batches fed over an 8- to 10-hour period to get a consistent chemical requirement for boiler water treatment. Once the boiler has stabilized and treatment test results remain reasonably balanced, testing may be required only every 4 hours.

At this time you can chart your chemical requirements, based on load demand on the boiler. By establishing this history through experimentation, your operators are able to treat the boiler water with fairly accurate results. At this time note that boiler blowdown has a big effect on your treatment program. Proper blowdown practices cannot be overemphasized. Too little blowdown causes TDS readings to be high; too much blowdown causes a high demand for chemicals and results in lost efficiency of the boiler.

MAINTENANCE

The subject of boiler maintenance covers a wide range of topics. Many of these topics, including renewing boiler tubes, repairing refractories, and repairing settings are discussed in *Utilitiesman 3 & 2*, volume 2, NAVEDTRA 10661. Major repairs that involve welding of

pressure parts of the boiler are done by Steelworkers in strict adherence to the procedures in section IX of the ASME (American Society of Mechanical Engineers), "Boiler and Pressure Vessel Code." This section is mainly concerned with operator and preventive maintenance and major considerations for the maintenance and care of firesides and watersides. Procedures for laying up idle boilers are also discussed.

OPERATOR MAINTENANCE

Operator maintenance is the necessary, routine, recurring maintenance work performed by the operators to keep the equipment in such condition that it may be continuously used, at its original or designed capacity and efficiency, for its intended purposes.

The operator is actually the most important member of the maintenance team. A well-informed and responsible operator can

1. keep equipment in service for maximum periods of time;
2. detect any flaws so that equipment is removed from service in time to prevent serious damages; and
3. perform minor repairs on equipment removed from service so as to minimize outage time.

It is sometimes difficult to determine where operator duties end and maintenance crew work begins. However, the operator must realize that he has the keenest interest in the condition of the equipment. A well-kept plant not only reflects the operator's interest (and the desire to better his or her position), but it is vital to the safety of equipment and personnel. It is essential that every person in the operating aisle perform the following duties:

1. Clean. Dirt is the principal cause of equipment failure. Whether it is fly ash in the switch gear, oil on the deck, cloth lint, or dust, it will cause trouble. No matter the form in which dirt appears, it should be removed immediately by the operator.
2. Lubricate. Any two surfaces brought together develop friction. If not properly lubricated, these surfaces wear one another down, change clearances, and cause equipment breakdowns. A well-placed drop of oil or thin layer of grease can go a long way toward keeping a much used piece of equipment in good condition.

3. Cool. Every piece of equipment has an operating temperature range. The operator should be informed on this matter. Any unusual temperature change that the operator cannot correct should be reported immediately to the plant supervisor. When the temperature of a piece of equipment rises rapidly, an immediate shutdown is recommended.

4. Tighten. Vibration is another major source of equipment failure. A simple step taken in time, such as tightening of bolts, can prevent a serious failure. Equipment that is not properly secured vibrates, causes an unbalance, vibrates further, and compounds a cycle that can only lead to further trouble. In making rounds, the operator should put his hand on the bearings, touch the fan housing, and feel the motor casing. When any unusual sound is heard, vibration felt, or motion seen, the proper steps should be taken by the operator to correct the condition.

PREVENTIVE MAINTENANCE

Preventive maintenance is a system of routine inspections of equipment recorded for future reference on some type of inspection record. Its purpose is to anticipate and prevent possible equipment failures by making periodic inspections and minor repairs in advance of major operating difficulties.

Preventive maintenance is the responsibility of both operators and specified maintenance crews. The operator is expected to do as much maintenance as is within his technical abilities, for which tools are adequate, and for which time allows. Specifically assigned maintenance crews work on equipment requiring no operator, or where the work to be done is beyond the scope of the operator. Since preventive maintenance is so vital, it is essential that duties and responsibilities be clearly defined. It is easy, and quite natural, to fall into the "let George do it" pattern. An effective maintenance group functions well only when clear responsibility is established.

Scheduling of preventive maintenance is the responsibility of the plant supervisor. The supervisor should maintain a record card for each major piece of equipment, its PM schedule, and its record of PM inspections and operations with the results recorded thereon.

MAINTENANCE PROGRAMS

The problem of maintenance should be approached with the view of how much it will

cost *not* to carry on an active maintenance program. The unexpected expenses are sure to be far greater in frequency and extent when such a program is abandoned or deferred than when it is in effect.

Large plants use a card-index system. One card is made out for each piece of equipment and contains identification information and a space for entering records of tests and remarks. Sometimes, a signaling system can be used to indicate the date on which equipment is due for tests, overhauls, and inspection. Even the smallest plant can create an alphabetical card-index file system to furnish this information.

Preventive maintenance in an industrial boiler plant is greatly influenced by legal requirements and is performed to protect personnel and to prevent equipment damage that could lead to costly repairs and loss of productive capacity. In fact, preventive maintenance directed *specifically* to maintaining boiler efficiency is the exception rather than the rule. Rising fuel costs have placed an increasing emphasis on conscientious maintenance because it results in higher boiler operating efficiency. These preventive maintenance practices are often easily justified from an economic standpoint.

Efficiency-related boiler maintenance is directed at correcting any condition that increases the amount of fuel required to generate a given quantity of steam. Thus, at a specified boiler load, any condition that leads to an increase in (1) flue-gas temperature; (2) flue-gas flow; (3) combustibles content of ash or flue gas; (4) convection or radiation losses from the boiler exterior, ductwork, or pipe; or (5) blowdown rates is considered an efficiency-related maintenance item. Generally, attention to such items can also forestall more serious consequences, such as damage to equipment and/or injury to personnel.

The boiler tune-up is one of the most effective means for improving efficiency and for maintaining it at a high level. The primary objective of a tune-up is to achieve efficient combustion with a controlled amount of excess air, thus reducing the dry-gas loss and the power consumption of forced- and induced-draft fans.

A log in which each operator can keep hourly readings and remarks of any unusual occurrence is also of value. The value is enhanced by recording notes on readings and observations from the more remote parts of the plant that may seldom be visited during the normal course of duties. An operator hesitates to walk past equipment to take a reading without observing its condition.

Individual boilers should have a log to record the operation and performance of controls and safety devices. The minimum tests and checks shown assist operators in determining whether the boiler and its controls are in good operating condition. The tests must be performed at established frequencies, and if any malfunctions are found, they should be corrected immediately. A boiler with a defective safety valve, improper water-level control, or nonoperating low-water fuel cutoff should never be operated unattended until these vital devices are in good working order.

Log sheets are a forced reminder to check certain components of a boiler to prevent trouble from developing later and to note if proper operation is taking place. A log sheet should be used to record all important operating data, such as pressures and temperatures. The log sheet should also be used to record procedures such as the time at which the soot blowers and water columns are blown and when blowdown valves are operated. A continuous record of operating data and important procedures carried out is then at hand when needed. It is also important to log the testing of safety appurtenances.

Any irregular operation or event should be recorded in a separate book, with a description of the irregularity and the corrective measures taken. In this book all orders should be written and initiated by the operator.

Operators reporting for duty should read the annotations made by the previous watches. Then the oncoming operators are informed as to what the past operation has been, what orders have been issued for future operation, and what trouble spots to watch for. They should then initial those items for which they are responsible to indicate that they are familiar with the situation. Log sheets are supplied by some insurance companies for small low-pressure plants and industrial high-pressure boilers. Many plant operators design their own log sheets to record important data pertaining to their specific plant's details and layout.

CARE OF BOILER FIRESIDES

The boiler firesides must be kept clean. The burning of any petroleum product tends to be incomplete, thus leaving soot and carbon deposits on the boiler firesides. These deposits seriously reduce the efficiency of a boiler. Slag contributes greatly to failure of such parts as superheater support plates, baffles, protection plates, and soot blowers. Deposits also act as insulation and

prevent the transfer of heat to the water or steam in the tubes.

Soot and slag accumulations that block the gas passages through the tube banks require the use of high air pressures to force the combustion gases through the boiler, thus reducing fireroom efficiency. Accumulations that block the gas passages also interfere with the designed flow of combustion gases and cause extremely hot gases to pass over protection plates, baffles, seal plates, and other parts that are not designed for such high-temperature gases; in some cases, early failure of these parts can be blamed directly on blocked gas passages and the resulting overheating of the parts.

When soot is allowed to remain on the boiler firesides for any length of time, the sulfur in the soot combines with moisture and forms sulfuric acid. This acid attacks tubes, drums, and headers. The extent of the damage caused by acid attack depends upon the length of time the soot remains on the tubes and upon the amount of moisture present during this interval. Moisture may be present as a result of high atmospheric humidity; rain or snow coming down the stack; leaky boiler tubes; and steam or water leakage through the boiler casing joints, particularly from machinery and piping installed above the boiler.

One indication of soot corrosion is the development of pinhole leaks at the point where the tubes enter the water drums and headers and at other points where it is difficult to clean the tubes properly. When soot corrosion is allowed to proceed unchecked, extensive deterioration of the boiler metals results.

You will find that keeping the firesides clean actually saves work, as well as saving the boiler. Clean tubes do not collect deposits as readily as dirty tubes do. It is a good deal easier to clean the firesides several times when they are only slightly dirty than to clean them once when they are heavily coated with soot and carbon.

Local instructions usually specify steaming intervals after which the boiler firesides must be cleaned. In addition to this upkeep, the firesides are normally cleaned just before to the annual internal inspection.

Although there are a number of cleaning methods available (such as hot-water washing, wet-steam lancing, and so forth), mechanical cleaning should be considered the basic and preferred method of cleaning firesides. The other methods are generally used only when mechanical cleaning cannot adequately remove the fireside deposit.

Mechanical cleaning is accomplished within the boiler, in the furnace, and from outside the boiler through access doors by using various types of scrapers, probes, and wire brushes to remove soot and other deposits. In most instances, these cleaning tools can be obtained from the boiler manufacturer.

In addition to scrubbing and cleaning the firesides of the generating tubes, other areas of the firesides should receive scrupulous cleaning as well. Particular care should be given to those more or less inaccessible portions of the firesides that are not cleansed by the soot blowers. Any encrusted soot should be removed from burner impeller plates, bladed cones, and drip pans. The furnace refractory must also be cleaned. This operation is perhaps best done last to remove not only original deposits from the brickwork but also soot and dust deposited after other parts of the boiler were cleaned. It is important to keep the brickwork clean for two reasons: First, soot and foreign matter lodged in expansion joints can obviously prevent proper expansion of refractories when hot, and can ultimately cause serious cracking of the brickwork; second, soot and other deposits left on the brickwork will lower the melting point of the refractories.

CARE OF BOILER WATERSIDES

Failure to keep boiler watersides clean reduces the efficiency of the boiler and contributes to overheating, thus leading to serious damage. Experience has shown that tube failures resulting from defective materials or poor fabrication are rare. The majority of all tube failures, other than those associated with water-level casualties, are caused by waterside deposits or accumulations. Some tube failures are caused by waterside deposits of hard scale. More frequently, however, tube failures occur as the result of an accumulation of relatively soft materials such as metal oxides, the residue of chemicals used for boiler water treatment, the solids formed as a result of the reactions between scale-forming salts or other impurities and the chemicals used for boiler water treatment.

As in the case of fireside cleaning, waterside cleaning is usually accomplished after specified steaming intervals and also before the annual internal inspection.

The need for cleaning watersides or firesides is often signaled by a gradual rise in the stack gas temperature. In other words, deposits on either the firesides or watersides of generating tubes

reduce heat transfer from the furnace to the water. A good part of the nontransferred heat is, as you know, retained by the fireside or waterside deposit. However, some of the heat not properly carried away by the water and not absorbed by the deposits remains with the combustion gases. Therefore, the temperature of the stack gas rises.

When working in the watersides of a boiler, you should take all possible precautions to keep tools, nuts, bolts, cigarette lighters, and other small objects from sliding down into the tubes. Some required precautions are as follows:

1. Remove all small objects from your pockets before entering the boiler.
2. Keep an inventory of all the tools and equipment you take into the boiler, and ensure that you remove each item and check it off the inventory before closing up the boiler.
3. Do NOT set tools or other articles down in places where you are likely to forget them. For example, you must *not* leave tools on top of the steam separators or in other places that are easy to reach but hard to see.
4. When an article is lost in the boiler watersides, you must *not* close up or operate the boiler until the article has been found and removed. Even a very small article can interfere with boiler circulation and cause tube ruptures.

Additional precautions for waterside work include the following:

1. Close, wire, and tag all steam, water, and air valves that could possibly admit fluids to the boiler. Disconnect (or otherwise render inoperative) the remote operating valves as well.
2. Be sure that adequate ventilation is provided before entering the watersides of a boiler.
3. Be sure that all portable extension lights are of the watertight globe type, with the globe encased in a rubberized, metal cage. Be sure that all lights are grounded and that wires are not broken. Examine the wires from end to end to be sure that the insulation is not broken or cracked, exposing the bare wire.
4. Station a person outside the drum whose ONLY duty is to act as tender and to assist personnel working in the drum.

Boiling out is a special waterside cleaning technique. There are two approved methods for boiling out boilers—the sodium metasilicate pentahydrate method and the trisodium phosphate method. The method to be used depends

upon the purpose of the boiling out. The sodium metasilicate pentahydrate method is used to remove rust-preventive compounds and other preservatives; consequently, this method is used for boiling out (1) newly erected boilers, (2) reactivated boilers, and (3) boilers that have had major tube renewals. The trisodium phosphate method is used when you are boiling out for the removal of oil and for scale softening in preparation for mechanical cleaning.

LAYING UP IDLE BOILERS

Many operators faithfully and carefully follow all the procedures and regulations concerning boiler water treatment, only to find that the watersides nevertheless experience corrosion and pitting. It should come as no great surprise that the fault is not with the treatment methods, but rather the manner in which the boiler is permitted to stand idle.

After the pressure drops within an idle boiler, air gradually seeps into the boiler, carrying oxygen with it. The air also contains carbon dioxide that combines with the boiler water to form carbonic acid, which, in turn, lowers the residual causticity of the boiler water. Gradual in-leakage of feedwater can dilute and lower the causticity of the boiler water even further. In addition, condensation within the boiler, on both watersides and firesides, can produce water droplets that are saturated with oxygen and contain no causticity. Conditions within the boiler are now ideal for active and rapid corrosion.

The need for protecting boilers that are left idle for any length of time should be obvious. There are two principal methods by which idle boilers may be protected: WET LAY-UP and DRY LAY-UP.

In the wet method, the boiler is filled to the steam takeoff with water treated so that it carries as much as 200 ppm of causticity, is free of oxygen, and is uniform in chemical composition throughout. Additionally, it is sometimes desirable that the water be treated with about 100 ppm of sodium sulfite to take up any oxygen that may get into the water. By keeping the boiler completely filled, you can avoid air in-leakage and waterline pitting. Chemical concentrations must be distributed uniformly throughout the boiler to prevent an electrolytic type of corrosion. The best way to mix the chemicals with the water is to use some scheme of circulation for a short time. This should be checked by testing a sample of the boiler water, and the sampling and testing should be

repeated once a week as long as the boiler is idle.

In the dry method, the boiler is emptied, dried, closed, and kept thoroughly dry by use of quicklime inside the boiler.

The wet method is usually considered more suitable for boilers left idle for a short period, say a month or less, or where there may be an unexpected demand for steam so that the boiler can be put back into operation more quickly. For longer idle periods, say 3 months or more, the dry method frequently is considered more desirable because it does not require as much care and control. When the entire plant is laid up and freezing weather is anticipated, only the dry method should be used.

Laying Up a Boiler by the Wet Method

The feedwater used to fill the boiler is deaerated as much as possible. While the boiler is being filled, caustic soda and, where used, sodium sulfite are fed into the boiler by continuous feeding. In this way, uniform distribution of the chemical throughout the boiler is obtained. About 1 ounce of caustic soda and 0.2 ounce of sodium sulfite are used for every 100 pounds of water, giving about 200 ppm of causticity and about 100 ppm of sodium sulfite in the boiler water. When equipment is installed in a plant and used in acid treatment of the feedwater, it should never be used to fill a boiler for idle standby; this results in a low pH in the boiler, as concentration by boiling is taking place. To ensure the boiler is filled completely, you should add water until it overflows at the top of the boiler through any convenient outlet, and then close the outlet. When there is a superheater on the boiler, add water to fill it completely. If appreciable air is dissolved in the water, you should boil the water to vent out any air after the boiler is nearly filled.

When the chemical feeding setup installed is not suitable for continuous feeding and it is necessary to slug-feed the chemical while the boiler is being filled, the boiler water must be mixed to get uniform distribution of the chemical throughout the boiler. This can be done by use of a circulating pump to pump water from one section of the boiler to another. Where such a pump is not available, mixing can be accomplished by heating the boiler water just enough, as by a light wood fire, to set up natural circulation.

After a boiler has been filled for standby, it must be kept filled as long as it is idle, with no

water flowing either out of or into the boiler. Leakage out, as through a leaky blowdown valve, can admit air and form a waterline in the boiler. In-leakage of feedwater or condensed steam gives differences in chemical concentration between different parts of the boiler. To avoid such leakage, it is sometimes necessary to blank off the feedwater inlet of the steam line.

A method sometimes used for keeping a boiler completely full consists of using a small tank placed above the boiler with a line connected to any outlet at the top of the boiler or the superheater header. This method also shows when any leakage occurs either into or out of the boiler. The small tank is provided with a vent and a water column. When the boiler is filled, water is added up into the tank. Then, if any water leaks out of the boiler, water from the tank flows in, keeping the boiler full. In-leakage of air due to shrinkage by cooling of the water in the boiler is also prevented. When the level in the tank rises, it shows that water is leaking into the boiler, either through the feed line or the steam line.

Water in an idle boiler should be sampled and analyzed at about 1-week intervals. When the causticity or the concentration of sulfite is found to have dropped considerably, you should ensure additional chemical is fed and the boiler water circulated to distribute the chemical uniformly.

One disadvantage of using the wet method is that when the temperature of the water in the boiler is lower than the outside temperature, condensation or moisture occurs on the outside of the metal boiler, causing corrosion. Some engineers, therefore, coat the outside of the metal boiler with light oil to help protect it from corrosion.

Laying Up a Boiler by the Dry Method

Dry lay-up is a much surer way of preventing corrosion in idle boilers. The boiler is emptied completely when the setting has cooled, and the boiler is cleaned with water to remove sludge. The boiler is then dried carefully and thoroughly with a wood fire or by other means, as recommended by the boilermaker. To avoid leakage of water into the boiler, you may need to blank off the feedwater lines and steam lines. Place a suitable chemical drying agent that can absorb moisture from the air in the boiler to keep it thoroughly dry, and then close the boiler tightly. The drying agent commonly used for this purpose is quicklime. It can be placed on any convenient tray or

board arrangement in the boiler. At least 20 pounds should be used for every 100 boiler-horsepower.

A certain quantity of quicklime can take up only so much moisture, after which it becomes exhausted. Therefore, the boiler should be opened at about 3-month intervals to inspect the quicklime. If moist, the quicklime must be replenished or replaced. Leakage of steam or feedwater into the boiler can exhaust the quicklime rapidly.

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CHAPTER 13

DUCT AND VENTILATION SYSTEMS

Learning Objective: Identify the factors that influence the installation of duct and ventilation systems.

As a senior Utilitiesman, you can expect to become involved in the installation of duct and/or ventilation systems designed to provide conditioned air or to remove less desirable air from a given space or facility. When sheet metal is to be fabricated into system components, the Steelworker will provide the expertise. When duct board is used, fabrication and installation may be tasked to the Utilitiesman exclusively.

This chapter will provide some key knowledge to aid you in the identification of types of duct and ventilation systems, their installation, and factors you must be aware of in determining the sizes required to meet specified building requirements. Keep in mind that the term *air-conditioned* refers to air that has been cooled, heated, dehumidified or humidified, or any combination of these.

DUCT SYSTEMS

To deliver air to the conditioned space, air carriers are needed. These carriers are called ducts. They are made of sheet metal or some structural material that will not burn (noncombustible).

Ducts systems are also classified as high-pressure or high-velocity ductwork and low-pressure or low-velocity ductwork.

The term *high-pressure* or *high-velocity* ductwork includes ductwork systems and plenums from the fan discharge to the final high-velocity mixing boxes, or other final pressure-reducing devices or any air supply system served by a fan operating with a static pressure range of 3 inches to 7 inches of water column (WC).

High-velocity or high-pressure systems with fan static pressures of 3 inches WC or greater are defined as high pressure. Usually the static pressure is limited to a maximum of 7 inches WC and duct velocities are limited to 4,000 feet per minute (fpm). Systems requiring pressures in excess of 7 inches WC are normally unwarranted and could result in very high operating costs. Systems with velocities in excess of 4,000 fpm perform satisfactorily when all duct fittings are carefully designed and installed. However, velocity pressure losses are excessive in most cases and velocities in excess of 4,000 fpm are not recommended.

A high-velocity double duct system begins with a high-pressure fan of class II or III design and conveys air through sound-treated high-velocity ductwork connected to sound and pressure-attenuating mixing units. Connections to the outlets of the reduction units are treated as low velocity.

Smaller-sized ductwork using higher velocities permits conveyance of air to areas limited by construction and reduces floor-to-floor heights in most cases. Round ductwork generally provides the greatest strength, tightness, and economy. However, oval and rectangular ducts can be used when large risers are involved.

A necessary component of the high-pressure system is the mixing box or unit. Its function is to blend air at two different temperatures for proper delivery to the rooms. This requires special pressure-reducing air valves at both hot and cold inlets, mixing baffles to prevent stratification of air, and sound attenuation treatment to absorb noise generated by the air valves.

Table 13-1.—Outlet Velocities for Optimum Performance of Fans

STATIC PRESSURE INCHES OF WATER	CENTRIFUGAL FANS OUTLET VELOCITY fpm	TUBEAXIAL AND VANEAXIAL FANS OUTLET VELOCITY AT WHEEL DIA. fpm
1/4	400- 100	950-1,500
1/2	550-1,450	1,350-1,900
3/4	700-1,750	1,650-2,350
1	800-2,000	1,900-2,700
1 1/2	1,000-2,500	2,350-3,300
2	1,150-2,800	2,700-3,800
2 1/2	1,250-3,200	3,000-4,300
3	1,400-3,500	3,300-4,700
4	1,600-4,050	
6	2,000-4,950	
8	2,300-5,700	
10	2,500-6,400	

The term *low-pressure* or *low-velocity* duct-work applies to systems with fan static pressures less than 3 inches WC. Generally, duct velocities are less than 2,000 feet per minute.

The choice between the use of low versus high-velocity systems requires architectural, mechanical, and structural considerations. Installation cost, temperature control, and operating cost should also be studied.

Low-velocity double duct systems are many years old. It was not until after World War II that their use became extensive. Space for the installation of the double ducts is a main consideration for this system and must be provided during initial planning. Difficulties in providing for this space in modern structures with low floor-to-floor heights and flush ceilings, together with the need for developing a compact distribution system for existing buildings, has brought about the development of high-velocity double duct systems. High velocity saves ceiling space and duct shaft

space, but requires greater attention in the selection of fans and equipment with regard to sound levels. Also, higher duct velocities require increased fan static pressures; therefore, increased operating costs. On the other hand, high-velocity systems are easy to balance and control and have much greater flexibility for partition changes and so forth.

Generally, high-velocity systems are applicable to large multistory buildings; primarily because the advantage of saving in duct shafts and floor-to-floor heights is more substantial. Small two- and three-story buildings are normally low velocity; however, both systems should be analyzed for each building. Table 13-1 shows outlet velocities for the range of optimum performance of typical ventilation fans.

Ducts are made of many types of materials. Pressure in the ducts is small, so materials with a great deal of strength are not needed. Originally, hot air ducts were thin, tinned sheet steel. Later, galvanized sheet steel, aluminum sheet, and

Table 13-2.—Materials for Ductwork

Application	Material
Normal system handling dry air	Galvanized Steel Fiberboard
1. Air conditioning 2. Ventilating	
System handling air at very high temperature	Black Steel
1. Kitchen exhaust	
Systems handling partly saturated air	Aluminum
1. Outside air intake ductwork 2. Exhaust ductwork near discharge outlet 3. Ductwork exposed to weather elements	
Systems handling completely saturated air	Copper
1. Shower exhaust 2. Dishwasher exhaust 3. Ductwork exposed to salty atmosphere	

finally, insulated ducts made from materials such as asbestos and fiberboard were developed. Passageways, formed by studs or joists, are sometimes used for return air where a fire hazard does not exist.

Ducts made of asbestos are no longer legal. If discovered, asbestos in any form must be removed and disposed of according to the laws and regulations discussed in chapter 15 of this manual.

The material used for the construction of ductwork depends on the application of the duct. Use table 13-2 as a guide in the selection of duct material. The thickness of the material depends primarily on the pressure developed within the duct, the length of the individual sections, and the cross-sectional area of the duct. The developed length of a section for a particular gauge can be increased by installing angle bracing around the duct. It is beyond the scope of this manual to include the technical details necessary for the

selection of proper metal thickness and section length for different pressures and for different cross-sectional areas of duct material. However, when repairs are made, the same thickness of metal that was originally included in the system must be installed. Where the original ductwork was destroyed by pressure, repairs may include increasing metal thickness or adding of angle bracing.

Ducts are either round or rectangular in cross section. Although rectangular ducts usually have the advantage of saving room space and being easier to install in walls, round ducts provide less resistance to airflow and should be used whenever possible.

Additionally, round ducts require less material to construct; thus by using round ducts, you can save both money and material during installation.

Initially, an air-handling duct system is usually sized for round ducts. Then, if rectangular ducts are desired or required, duct sizes can be selected to provide flow rates equivalent to those of the round ducts originally selected.

Table 13-3 is a ready reference to determine the size of a rectangular duct that equals the carrying capacity of a predetermined round duct. To use this chart, convert a rectangular duct with sides of 17 inches by 16 inches, respectively. First, come down the left-hand column until you reach 17 inches; then, trace the line horizontally across the columns until you reach the column headed by 16 inches. At the center of these intersecting lines is 18.0 inches. This is the round duct size equivalent. In the second example, following the same procedure, it is clearly shown that a 22-inch by 17-inch rectangular duct has a 21-inch round duct equivalent. The formula located in the bottom left-hand corner of table 13-3 is the basis for this chart. This formula can be used to convert any size rectangular duct to an equivalent size round duct.

TYPES OF DUCT SYSTEMS

In this section, the advantages and disadvantages of a double duct system are discussed. Since there are numerous possibilities for an adequate duct system, one such system is modified to fit the needs of two different residential configurations.

Dimensions in inches

Chart determines sizes of rectangular ducts necessary to equal carrying capacity of round ducts. To use, find the diameter of the round pipe in the chart. Then find one side of rectangular duct by reading up. Find the other side by reading left to the first row of numbers representing the other side of the rectangular pipe.

A double duct system generally consists of a blowthrough fan unit discharging filtered air through stacked or adjacent heating and cooling coils into separate plenums and ductwork with thermostatically controlled mixing dampers at various room locations.

The inherent advantage of a double duct system is that individual room conditions can be maintained from a central system, within the limitations of supply air temperatures. This is done by the blending of hot and cool air through automatically controlled mixing devices. Another important credit is flexibility. In this regard, individually controlled rooms can be easily incorporated, at modest cost, after the building is completed.

In modern buildings of multiple exposures designed for variable functions and changing occupancy, individual room control is essential and a double duct system should be seriously considered.

Double duct systems for low pressure are usually tiered hot and cold ducts within the furred space. They are generally located above corridors. The manner of distributing proper temperature air to the room is through right angle, interlinked

mixing dampers operated by motors controlled through thermostats. In general, this type of system uses the same corridor plenum area around the ducts for conveyance of return or exhaust air. The residual volume of space left for this purpose is too often neglected. Inevitably, this results in insufficient relief for the rooms.

The main disadvantage of a double duct system is lack of stability of air quantities supplied to areas (rooms) because of varying duct static pressures.

All duct elbows, including supply, exhaust, and return, should be made with a center line radius of 1.5 times the duct width, parallel to the radius wherever possible. In no case should the center line radius be less than the width of the duct parallel to the radius. Where space does not permit the above radius, or where square elbows are indicated on plans, turning vanes of an approved type should be used.

Additionally, there are numerous adaptations and modifications of duct systems. Figure 13-1 shows a residential duct system with the furnace and central air unit located in the basement.

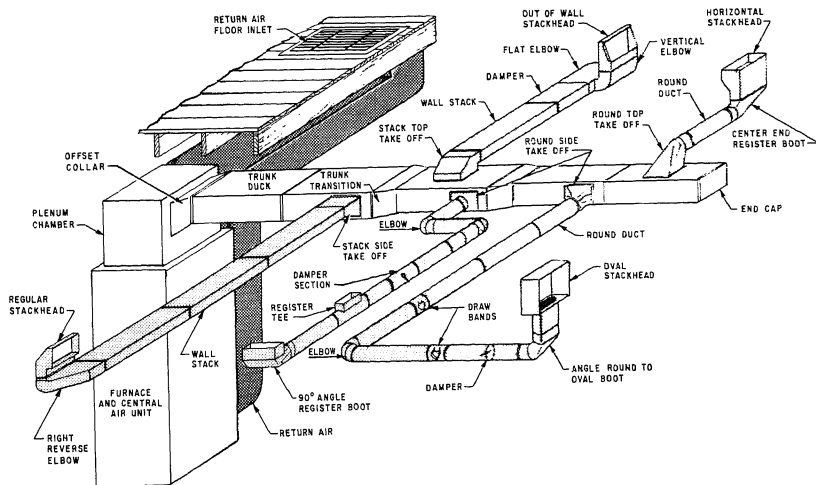


Figure 13-1.—Residential duct system.

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In figure 13-2, the same basic system is shown in a single-story house. The duct system is located in the overhead and the return air enters through the bottom of the central air-handling unit. When the duct system is located in a crawl space, basement, or attic, it should be insulated to maintain the existing temperature.

DUCT CONSTRUCTION

In this section, basic sheet metal duct both round and rectangular is discussed. Emphasis is placed on layout and pattern requirements. Then, fiberboard duct construction and its use are discussed.

Round Duct

Straight sections of round duct are usually formed from sheets that are rolled to proper radius and assembled with a longitudinal grooved seam. Each end of a round section is swaged and assembled with the larger end of the adjoining section butting against the swage. Sections are held together by rivets, by sheet metal screws, or by solder. Where solder is not used, duct tape should be employed as a covering at all joints. Rectangular ducts are generally constructed by bending corners and by grooving along the longitudinal seam.

The duct system should be constructed in such a manner as to avoid abrupt changes in size,

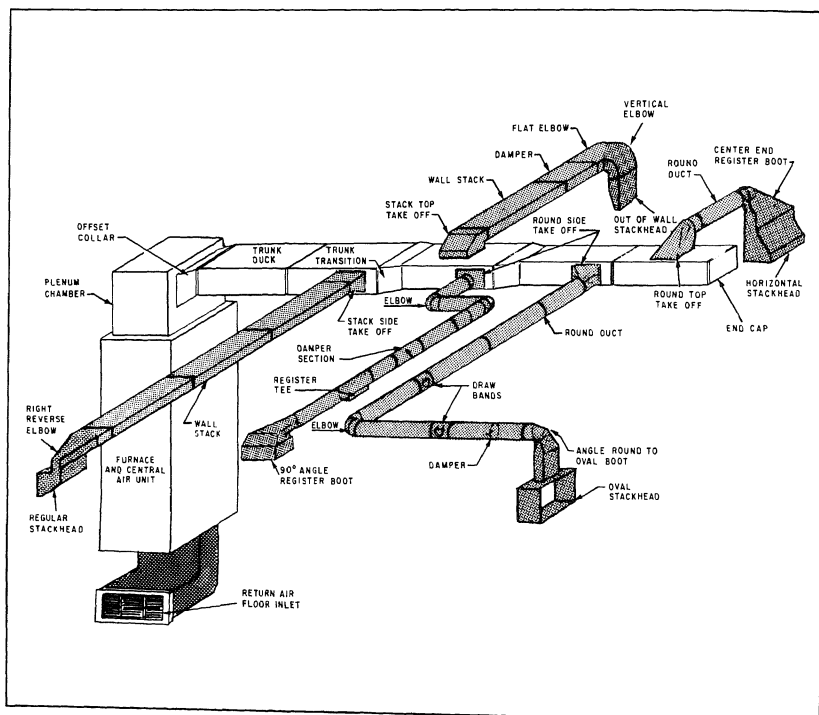


Figure 13-2.—Residential duct system.

87.421

direction, or other resistance conditions that can create unnecessary noise and reduce the air volume. The normal noise level of air flowing through a duct depends on the velocity of the air moving through the duct. This can be further reduced by lining or covering the duct with sound-absorbing material. The exterior of ducts that carry conditioned air can be covered with heat insulation materials to prevent heat transfer between ducts and the surrounding air. All materials used for duct lining and coverings must be noncombustible.

Ducts should be constructed for easy maintenance. They should have access plates or doors included to facilitate cleaning and inspection. It is important that the correct size duct (as specified on the prints or drawings) be used for the construction of the duct system. The amount of air to be carried depends on the size of the duct. This determines the pressure loss in the system—the larger the quantity of air moving through a duct of a given cross-sectional area, the greater the friction loss. Similarly, with a given quantity of air to be delivered, the friction loss increases in inverse proportion to the sizes of ducts provided to carry the air. Therefore, the power required at the fan for delivering a given quantity of air increases rapidly as the duct size is decreased. It is important to bear these facts in mind when it is necessary to replace or to change sections of ducts. The same size new duct should be used unless proper design provisions are made for a change in size.

Rectangular Duct

Straight sections of rectangular duct are normally formed by personnel in the Steelworker rating. This is normally accomplished on bending-brake type of equipment. Then the rectangular ductwork is joined together as mentioned earlier.

Straight sections of ducts can usually be laid out without a pattern. However, elbows, transitions, jump fittings, and so forth, require a pattern. While Steelworkers perform the task, you, as a planner, need to be aware of the time required to draw and fabricate the required patterns. Also bear in mind that if this is a one-time job, you can make the pattern of paper or cardboard. When there

are large numbers of the same size and dimension fittings to be constructed, you should make the pattern of sheet metal.

Fiber Glass Duct

A fiber glass duct is constructed of molded glass fibers covered with a thin film coating. This coating is usually of aluminum, but vinyl or other plastic coatings are sometimes used. Since they are made of glass fibers, the ducts are inherently insulated. Also, they are primarily used where insulation is a factor. Fiber glass meets military specifications for a flame spread rating of less than 25 and a smoke development rating of less than 50 for insulating material. The thickness of fiber glass ducts allowed for use in Navy installations must range between 3/4 inch to 2 inches, depending upon the size of the duct.

The nature of a fiber glass duct requires that it be supported with 1-inch by 1/16-inch galvanized steel strap hangers shaped to fit the duct. For round ducts, these supports must be on not less than 6-foot centers. Rectangular and square ducts up to 24-inch spans may be supported on 8-foot centers. Ducts larger than 24 inches require support on 4-foot centers.

The applicability of fiber glass ducts on heating systems is sometimes limited by the adhesive used on the protective outer covering to cause it to adhere to the fiber glass material. Unless aluminum surface duct is used, the specification of the duct should be checked carefully to ensure that it does not fail when heated over 250°F.

Fiber glass ducts can be molded into a variety of shapes for special uses. Round ducts and reducers are available from manufacturers' stock. For most purposes, however, the duct is supplied flat in the form of a board, with V-grooves cut into the inner surface to allow folding to make a rectangular section. The ends of the boards are molded so that when the rectangular duct is formed, two sections of the same size fit together in a shiplap joint to ensure a tight joint in positive alignment. It is important to exercise care in selecting a board of adequate size to complete the desired duct before beginning cutting and

grooving operations. In all cases, the inside diameter of the duct is the determining factor for board size. To determine board size see table 13-4.

To form a rectangular duct, the flat duct board is measured accurately and grooves are cut at the proper locations. The board is then folded into a rectangular shape. When the board is cut, an overlapping tab is left and this is then pulled tight and stapled. Tape is applied and the joint is heat sealed. Joints between sections are made by pulling the shiplap end sections together.

The joint is then completed by stapling, taping, and heat sealing the junction as shown in figure 13-3.

Sheet metal ducts expand as they become hot and contract as they become cold. The degree to which expansion and contraction becomes an installation factor depends upon the temperature of the air surrounding the ducts and the temperature of the air moving through the ducts. Fabric joints are often used to absorb this duct movement. Additionally, fan noise and furnace or air-conditioner noise tends to travel along the

Table 13-4.—Duct Board Length Selection Chart

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
6	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76
7	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78
8	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80
9	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82
10	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84
11	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86
12	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88
13	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90
14	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92
15	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94
16	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96
17	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98
18	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
19	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102
20	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104
21	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106
22	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108
23	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
24	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112
25	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114
26	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116
27	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118
28	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120
29	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	
30	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120		
31	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120			
32	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120				
33	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120					
34	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120						
35	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120							
36	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120								
37	94	96	98	100	102	104	106	108	110	112	114	116	118	120									
38	96	98	100	102	104	106	108	110	112	114	116	118	120										
39	98	100	102	104	106	108	110	112	114	116	118	120											
40	100	102	104	106	108	110	112	114	116	118	120												
41	102	104	106	108	110	112	114	116	118	120													
42	104	106	108	110	112	114	116	118	120														
43	106	108	110	112	114	116	118	120															
44	108	110	112	114	116	118	120																
45	110	112	114	116	118	120																	
46	112	114	116	118	120																		
47	114	116	118	120																			
48	116	118	120																				
49	118	120																					
50	120																						

*For 1½-inch board—ADD 4 INCHES to these dimensions.

*For 3-inch board—ADD 8 INCHES to these dimensions.

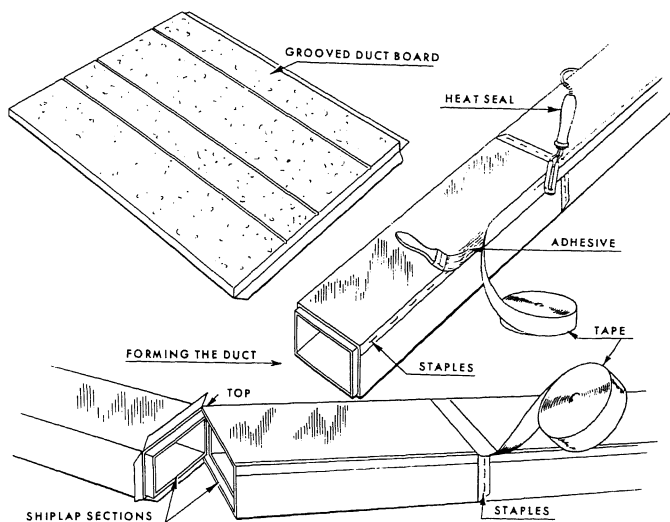


Figure 13-3.—Forming rectangular fiber glass ducts from duct board.

87.423

metal ducts. Therefore, fabric joints (usually constructed of heavy canvas) are used to join the branch ducts to the plenum.

SIZING DUCT SYSTEMS

There are numerous factors to be considered when sizing duct systems. These factors cause you to make modifications and adjustments throughout the planning and installation process to develop an efficient working system. First, you must calculate the air volume required for heating and for cooling the required space. This will assist you in determining the necessary duct size, fan size, fan speed, and so forth, that is needed to circulate the conditioned air. While determining the heating and the cooling factors, you should think in terms of air circulation throughout the building and in each individual room or space. Remember, air movement is determined by the type of return airflow that you use.

Four other important duct system components are diffusers, grilles, registers, and dampers. Each of these components has a direct correlation

between functional design, amount of air accommodated, and the air movement pattern.

The elbows within the duct system are a major source of airflow restriction. Whenever possible, you can gain efficiency by installing long sweeping elbows. Short 90-degree elbows should be used sparingly on long duct runs. However, they can be used very effectively with a minimum of air turbulence and airflow restriction when installed just before diffusers, grilles, and registers.

Your final duct calculations involve taking unit pressure drops and total pressure drops throughout the system. Some of the major contributing factors to these pressure drops are as follows:

- Length of duct
- Duct material and interior finish
- Changes in duct size
- Number of elbows

Normally, you will be installing a duct system according to preestablished blueprints and drawings. Occasionally you may need to refer to other sources and review trade association standards. The *ASHRAE Handbook of Fundamentals* has three chapters dedicated to methods and procedures for selecting proper duct sizes. You should become familiar with the contents of these three chapters; particularly, if you are involved in the design phase of an air-conditioning system.

BALANCING DUCT SYSTEMS

A duct system is always installed to fulfill specific requirement features related in some way to the health and welfare of human beings. Equally important is the fact that a properly balanced operating system results in lower operating costs and significant utilities conservation. Consequently, it is important that these systems, regardless of the function, operate properly. When a duct system is initially installed, the required pressures and performance data are available from the construction drawings and the manufacturer's instructions. After installation, pressures and performance requirements should be measured to ensure proper airflow at different locations. Once the proper airflows are established, little change should take place within the system. Maintenance personnel must ensure that the system is operating correctly by conducting certain periodic tests. Tests are used for the initial and subsequent setting of grilles, diffusers, dampers, and registers to obtain the necessary airflow required by specifications, codes, regulations, or trade association standards.

It is important to understand the pressure in a duct carrying a moving stream of air. Certain changes in an existing duct system are often necessary and you should be able to accomplish these changes. In addition, malfunctioning duct systems require immediate attention, and an understanding of the basic elements of the system is required before troubleshooting and corrective action can be undertaken. Furthermore, before a duct system can be properly balanced, certain essential knowledge of airflow is required.

Static pressure is a measure of the outward push of air on the walls of a duct. When air is not moving within a duct because a damper at the outlet is closed, the static pressure can be measured by means of a pressure gauge installed in the wall of the duct. If the damper in the duct is then opened and the air is flowing, static pressure continues to be present. It will be reduced

when the damper is opened, but the static pressure can still be read on the gauge.

When air is flowing in a duct, there is another pressure—in addition to the static pressure—that can be measured. This is the pressure exerted by the moving airstream. This pressure acts in a plane perpendicular to the direction of airflow. To illustrate, imagine a horizontal duct without any air flowing in it. When a thin, flat piece of metal is suspended with a movable hinge from the top of the duct, it will hang straight down when air is not moving. When air flows, the hinged piece of metal swings upward toward the top of the duct. The velocity pressure is the force that causes the deflection of the hinged vane (obviously, the greater the air velocity, the greater the pressure acting on the hinged vane and the greater its deflection from the perpendicular).

The velocity pressure cannot be measured as easily as the static pressure. When a hollow tube is inserted in the moving airstream, and a gauge is connected to the end of the tube, the gauge registers a certain pressure. This pressure is larger than the static pressure because the gauge indicates the sum of the static and the velocity pressure. This sum is known as the total pressure. Since

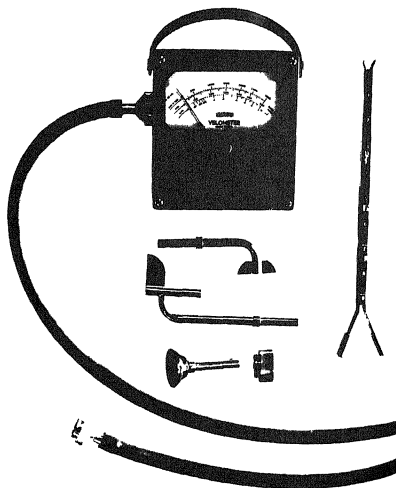


Figure 13-4.—Velometer set.

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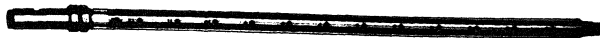


Figure 13-5.—Pitot probe.

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total and static pressure can be easily measured, the velocity pressure can be found by subtracting static from total pressure. In most problems concerning duct systems, air pressure is expressed in terms of inches of water (1 pound per square inch = 27.74 inches of water.)

At the time of initial installation of a duct system, the design data should be recorded. After initial start-up, the system should be balanced so that each air outlet is adjusted to the design rate of flow. During the initial balancing procedure, the actual design rate of flow is sometimes not achieved, but the flow is within the range of acceptable standards. When such conditions exist, they should be noted on the design data sheet where they may be considered by maintenance personnel during repairs or the rebalancing of the system. After the system is balanced and proper operation is assured, static pressure measurements are taken throughout the system. Also, the total pressure difference across the fan (the difference between the suction total pressure and the discharge total pressure) is noted. Although these initial measurements can be used for checking the design of the system, their main function is to serve as reference data for future tests. If the system fails to function properly at any time, another set of measurements should be taken and compared to the original set.

AIR BALANCING INSTRUMENTS

Numerous instruments designed for air balancing requirements are available from different manufacturers. Those that are most commonly used are discussed in this section.

Velometer

This instrument is particularly adaptable to maintenance work because of its portability, wide scale range, and instantaneous reading features. Its accuracy is suitable for most air velocity and static pressure readings. Since velometers are made by several manufacturers, the instruction sheets for any instrument should be thoroughly understood before attempting to use it. A

functional velometer set consists of the basic meter with hoses and accessories as shown in figure 13-4.

MEASURING DEVICES.—There are four measuring devices used with the basic meter for determining air velocities and pressures. They are the pitot probe, low flow probe, diffuser probe, and static pressure probe.

The pitot probe (fig. 13-5) is a stainless steel measuring probe with a standard length of 12 inches and a diameter of 1/2 inch. It is suitable for measuring velocities at supply openings and at return openings. Its primary purpose is to measure velocities within ducts. It is not recommended for velocity ranges below 300 fpm.

The low flow probe (fig. 13-6) is used for measuring velocities in open spaces. It connects directly to the meter and permits measurement of air by placing the instrument directly in the air currents. It is useful for measuring drafts in rooms and air velocities at ventilation hoods and spray



Figure 13-6.—Low flow probe.

87.258

booths. Only velocity ranges from 0 to 300 fpm are applicable to this device.

The diffuser probe (fig. 13-7) is used for measuring air output at duct supply diffusers. It can also be used with some meters on return air diffusers. The meter reading and the K factor established by the diffuser manufacturer can be used to determine air volume outputs.

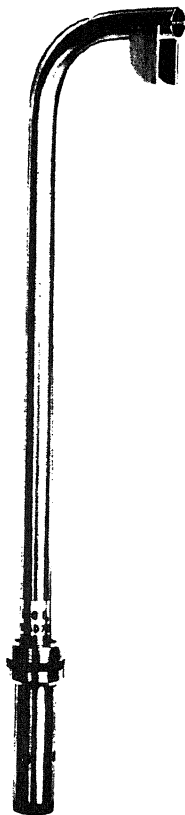


Figure 13-7.—Diffuser probe.

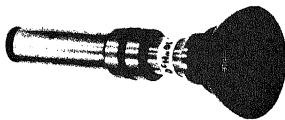
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The static pressure probe (fig. 13-8) is used for measuring drops across blowers or fans in duct systems. The probe is carefully placed over an opening in the wall of a duct so as to form a positive seal. The hole should not be less than one-quarter inch in diameter.

RANGE SELECTORS.—These are devices (fig. 13-9) that permit a rapid change of measuring ranges without the need for shifting to separate jets for each range. They are provided with connections that accept the various probes. These probes can also be connected to the meter. With the exception of the low flow probe, measurements may require a range selector.

Manometer

A manometer is an instrument that indicates air pressure by employing the principle of



87.260

Figure 13-8.—Static pressure probe.



87.261

Figure 13-9.—Range selector.

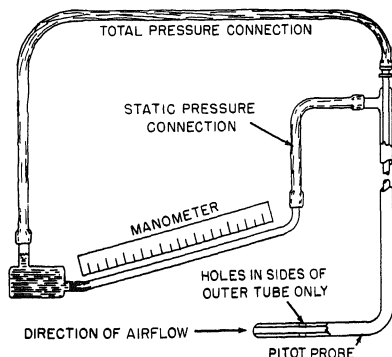
balancing a column of liquid of known weight against air pressure. The units of measure used are pounds per square inch, inches of mercury using mercury as the fluid, and inches of water using water as the fluid.

The simplest form of manometer is the basic U-tube type. Several variations of the basic type are presently used in air movement applications, for example, the inclined type (draft gauge) and the combination inclined and vertical type. An inclined manometer with a pitot probe is shown in figure 13-10. Many commercially installed central duct systems have permanently mounted manometers connected to duct interiors with static pressure tips.

Rotating Vane Anemometer

The rotating vane anemometer (fig. 13-11) consists of a propeller or revolving vane connected through a gear train to a set of recording dials that indicate the number of linear feet of air passing in a measured length of time. It requires correction factors and frequent calibrations, and it is not as accurate as the velometer.

The primary application for a rotating vane anemometer is the measurement of grille velocities on heating, cooling, and ventilating installations; however, it may not be suitable for exhaust measurements or for measurements on very small grilles.



87.179

Figure 13-10.—Inclined manometer with pitot probe.

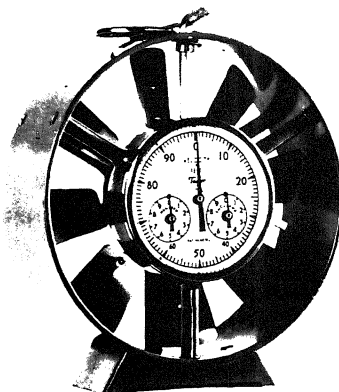
Miscellaneous Instruments

In addition to the air balancing instruments, there are other miscellaneous devices required. Thermometers are necessary for making temperature measurements at various duct and room locations; a tachometer is needed to determine fan speeds; and a multimeter is needed to check fan motors for proper operation.

PREPARATION FOR BALANCING

The following preliminary procedure is necessary before proper balancing can begin. These steps are general in nature and should apply to most situations.

1. Review applicable mechanical drawings and job specifications. This review will provide necessary data on the ducts, air handlers, and outlets. Information pertaining to design airflow can also be taken from these drawings.
2. Prepare a simple working sketch of the entire duct system showing dimensions, airflow volumes and velocities, and the location of all components such as dampers, fans, coils, and filters. Duct outlets should be numbered on the sketch starting at the farthest one from the fan



87.178

Figure 13-11.—Rotating vane anemometer.

and working back toward the fan. (See fig. 13-12.) The type of diffuser and the air delivery design of each outlet should be noted.

3. Obtain data pertinent to motors, fans, diffusers, and grilles that are not given on drawings. This can usually be taken from the manufacturer's identification plate located on the component. This information is useful during the balancing process for comparing measured results with design conditions.

4. Make a visual check of the system to ascertain that all fans are rotating correctly. Also, that air filters are clean and properly installed.

5. Place all dampers in the open position. This includes volume balancing dampers, splitter dampers, outlet dampers, and fire dampers.

6. Check all necessary instruments *prior* to starting the balancing procedure. Always follow the manufacturer's recommendations for checking the calibration of instruments.

PROCEDURES FOR BALANCING

The procedures required for balancing most systems are similar. Balancing is a rigorous technique that, if properly done, yields excellent results. As with any set of procedures, each operation is necessary and must be performed in the correct sequence. The following procedures are general in nature and apply to most systems.

Determine Fan Performance

The first step of the procedure is to determine fan performance. The purpose for this is to ensure that there is sufficient static pressure and air volume being handled at the fan before balancing is started. The fan's revolutions per minute (rpm), the voltage and amperage of the fan motor, the fan static pressure, and the system's total airflow are indications of fan performance.

The fan rpm can be measured by a tachometer as shown in figure 13-13. You should take several readings to ensure an accurate reading. The results can be compared with the design conditions to determine performance.

You should use a multimeter to determine if the operating voltage and amperage of the fan motor are within the range of rated voltage and amperage indicated on the motor nameplate. The measured results can either be compared or used to calculate the brake horsepower. Use the manufacturer's recommended calculation to determine the brake horsepower.

You can determine the fan static pressure by attaching a velometer and static pressure probe to test tap holes located on the inlet and discharge duct of the fan, as shown in figure 13-14. Fan static pressure is the static pressure at the outlet minus the total pressure in the fan inlet. This

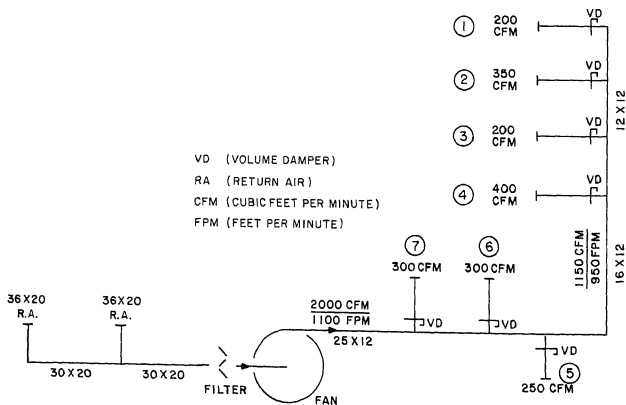


Figure 13-12.—Duct system working sketch.

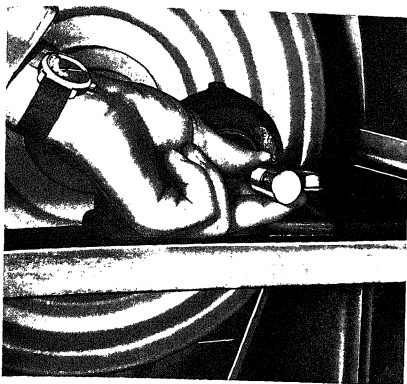


Figure 13-13.—Measuring fan rpm.

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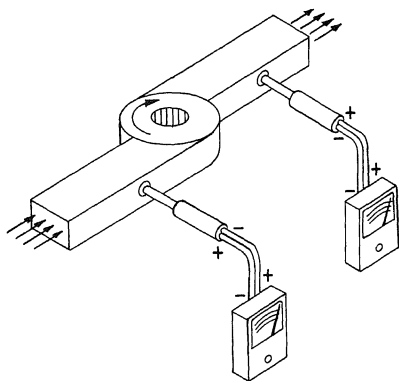


Figure 13-14.—Fan static pressure measurement.

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test may not be necessary in the field; however, if it is, the results can be compared with the manufacturer's fan curve and system specifications to determine fan performance.

You can quickly locate problems caused by blockages in duct systems by performing static pressure readings. The total air volume in

cubic feet per minute (cfm) for a fan can be determined by the following procedures:

1. Downstream of the air handler, establish a point along the duct that has the longest straight run and drill test holes into the duct. Holes should be far enough downstream from any elbows or from the fan discharge to minimize the effect of turbulence. The holes must be closed and sealed after the test is completed.

2. Take velocity pressure readings using a pitot probe and manometer or velometer. For rectangular ducts, velocity readings are taken at the center of equally divided areas. On round ducts, readings are taken across each of two diameters on lines at right angles to each other. (See fig. 13-15.)

3. Calculate the cubic feet of air per minute by multiplying the average velocity pressure in feet per minute found in the above reading by the cross-sectional area of the duct in square feet. Total airflow in cfm = Average velocity in fpm \times duct cross-sectional area in square feet.

The results are compared with design conditions to determine performance. Measured cfm should be approximately equal to design cfm plus 10 percent to allow for leakage.

In the event that fan performance is not consistent with design conditions, the necessary adjustments or repairs should be made at this point in the balancing procedure. For example,

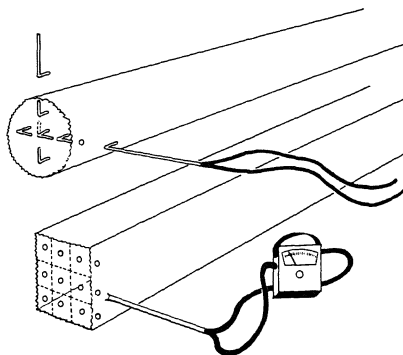


Figure 13-15.—Velocity pressure measurement.

87.265

the fan speed can be changed by adjusting the variable diameter motor pulley. Be careful to avoid operating the fan at a speed that overloads the motor. After adjustments or repairs, tests should be repeated to verify that the design conditions have been attained. Total air volume measurements should be repeated for all air-handling units on branch, return, and exhaust duct systems.

Duct and Outlet Adjustments

You should use the same procedure for measuring total air volume to set the main splitter dampers on systems containing branch ducts. When main ducts, zone ducts, and branches are set for design air, the tests necessary for adjusting individual outlets can begin. When available, always follow the manufacturer's recommended procedure.

The final balancing procedure involves the adjustment of individual outlets to correspond with the manufacturer's design flow and system specifications. Begin with the last outlet on the branch farthest from the fan discharge and measure the velocity (or cfm). You can use either a velometer with the diffuser probe or an anemometer. If the cfm is below design, leave the damper open and proceed to the next outlet. If the cfm is greater than design, close the damper to obtain the desired results. In the same branch go to the next closest outlet, repeat the procedure, then continue the process with each outlet until you reach the main duct.

If applicable, you should complete the same procedure on the remaining branch ducts. Finally, total cfm of all outlets should agree with total cfm of all branches, and this grand total should agree with the air volume for the fan or fans. These figures should be within 3 to 7 percent of design conditions. You should check fan outputs and motor amperages to ensure that the motor is not in an overloaded condition. At this point, fan speed and horsepower, fan total air by velocity measurement, and total air by outlet volume measurements have been established for the specific operating condition of the system during the procedure. The system should be balanced for those conditions.

VENTILATION SYSTEMS

Normally air contains about 21 percent oxygen. A ventilation system serving human

beings requires that a certain oxygen content be contained in the air to maintain life and to ensure comfort.

If a room is tightly sealed, any human in that room would slowly consume the oxygen and increase the amounts of carbon dioxide, water vapor, and various impurities. This could cause drowsiness or even death.

You must remember that space for human living must have air with a good oxygen content and that this air must be kept at a reasonable temperature. It is of utmost importance that fresh air be admitted to provide the oxygen.

In the past, this fresh air entered the space by infiltration (leakage) from the outside at door and window openings and through cracks in the structure. However, modern construction is reducing this air leakage. Air-conditioning apparatus, then, must furnish fresh air. Modern units have a controlled fresh-air intake. This fresh air is conditioned and mixed with the recirculated air before it reaches the room.

Some conditioned air leaves a building through doors, windows, and other construction joints. Some also leaves by exfiltration. (This means leaking out or being blown out by mechanical means.) Any kind of exhaust fan removes conditioned air. Some of this air is replaced by infiltration on those sides of the building exposed to wind pressure.

It is best to bring in replacement fresh air through a makeup air system. When this is done

- the makeup air can be cleaned.
- the makeup air can be cooled or heated.
- a positive pressure can be maintained in the building to keep out airborne dirt, dust, and pollen. (A negative pressure reduces the efficiency of exhaust fans and fuel-fired furnaces.)
- a definite amount of fresh air is brought into the building for health purposes (oxygen content).

Certain areas of a building should have a slightly less positive pressure (5 to 10 percent) than the rest of the building to reduce the spread of odors. Such areas would include the kitchen, lavatories, and where certain industrial operations produce fumes.

The amount of fresh air required depends on the use of the space and the amount of fresh air admitted by infiltration. One basic rule is to

provide at least 4 cfm of fresh air per person to provide enough oxygen and to remove carbon dioxide. If six people occupy a 1,000-square-foot space with a 10-foot ceiling, there is $10,000 \div 6$, or 1,667 cubic feet per hour for each person, or $1,667 \div 60 = 27.7$ cfm ($.78 \text{ m}^3/\text{min}$). This meets or exceeds ventilating code requirements.

One must remember that the air can be handled either to produce positive pressure (higher than atmospheric pressure) in a building or negative pressure (below atmospheric pressure). A positive pressure will eliminate infiltration of air from the outside or from other spaces. Positive pressure is produced by using special air intakes to the blowers. A positive pressure assures that all air entering a building can be filtered and cleaned before reaching the occupied space.

Negative pressure increases the infiltration at windows and doors. This air is untreated and may be dirty. If the amount of impurities in the inside air—such as odor, smoke, and bacteria—is great enough to require air cleaning, the remedy may be either more ventilation (using fresh air) or improved air cleaning.

Ventilation is usually based on air changes per hour for the conditioned space. If the space is 10,000 cubic feet for example, three changes per hour would mean 3,000 cubic feet per hour or 50 cfm. Three changes every hour is the minimum for a residence during the heating season. As high as 12 changes an hour (in the above case, 200 cfm) are recommended for cooling.

It is a good practice to keep the air blowers running all the time to provide good ventilation to all parts of the building. Variable speed blowers are sometimes used. They provide more air movement when the heating or cooling system is running and less movement when the systems are off.

An adequate air supply is the best way to control comfort. Body comfort is controlled by evaporation, convection, radiation, and respiration. You must, therefore, control the temperature of the walls, floors, or ceilings to make sure they are not too warm or too cold (radiation). You must also supply enough air to promote good respiration, evaporation, and convection. If the specified conditions are not known, it is best to design for 2 cubic feet per minute per square foot and/or 12 changes of air per hour. It is also very important to remember that people occupying a closed space give off considerable heat. A sleeping person gives off about 200 Btu/hr, while a person doing heavy work gives off up to 2,400 Btu/hr.

Another way to determine ventilation requirements is to design for 4 cfm to 6 cfm of fresh air per person and for about 25 cfm to 40 cfm of recirculated air per person. This means the system should handle a total of 29 cfm to 46 cfm per person. (1 cfm = $0.0283 \text{ cu m}/\text{min}$.)

NATURAL VENTILATION

Natural ventilation, or gravity ventilation, uses the natural forces of wind, stack effect, and breathing of structures caused by the interior-exterior temperature difference to induce air circulation and removal. Generally, air enters through openings at or near the floor level in a building and escapes through openings high in the walls or ventilators on the roof.

Natural ventilation is used only where the necessary quantity of ventilation can be induced by natural forces. Applications that require a continuous supply of outdoor air for human comfort, or the safe use of space (or process), should not be designed for natural ventilation. In such cases, natural ventilation is not reliable because of wide variations in the natural forces, such as wind velocity and direction, and the inside-outside temperature difference.

For an installation using natural ventilation, you should consider the location and control of ventilation openings. Locate the air inlet openings on the side of the building facing directly into the prevailing winds. Locate the air outlets where prevailing wind movements would create low-pressure areas; that is, on the side directly opposite the prevailing wind direction. Outlets may also be placed on a roof in the form of individual gravity ventilators, continuous monitors, or ridge ventilators. Calculate the ventilation rate due to wind velocity and the stack effect as detailed in criteria established by the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE). When natural ventilation is provided for temperature control, you should provide a means for closing the openings during the heating season.

The use of gravity ventilators is another method. A roof-mounted gravity ventilator may be a stationary, a pivoting wind-directional, or a rotating-turbine type of ventilator. You should select gravity ventilators based on the rating tables for the mounting height involved and a wind velocity of 4 miles per hour.

Natural ventilation has limited uses. In general, natural ventilation is inadequate for the following examples:

- Offices having an open window area less than 5 percent of the floor area
- Offices over 24 feet deep and without cross ventilation
- Offices having cross ventilation but having occupied space more than 35 feet from a window or an air inlet
- Dining rooms having a window area less than 6 percent of the floor area

In using natural ventilation, you should consider local building and safety codes and the minimum requirements of the Occupational Safety and Health Act (OSHA), part 1910.

MECHANICAL VENTILATION

Mechanical ventilation uses mechanical forces to induce air circulation within buildings or spaces. Air movement is created by fans, or by fans combined with a supply air and/or exhaust air duct system.

You should provide mechanical ventilation equipment where the necessary quantity of outside air cannot be supplied continuously by natural forces. The quantity of air supplied should be kept to the minimum acceptable.

You should install mechanical ventilation equipment in the following cases:

- For a supply of outside air and the removal of bad air or air contaminated by smoke, body odors, and so forth, in areas having a high

occupancy level (auditoriums, assembly halls, and cafeterias).

- For processes giving off noxious or hazardous fumes, dust, or vapor resulting in unsafe or unhygienic conditions (paint spray booths, electroplating plants, welding booths, and other similar applications).

- For limited comfort of operators as in laundries, projection booths, and kitchens.

- For spaces containing fumes and vapor with specific gravity higher than air, such as garages and some refrigeration rooms. In these cases, provide exhaust intakes at floor level.

- For electronic or electric equipment installed in confined spaces where the operating temperatures of the equipment may exceed the safe limit.

- For spaces having explosive vapors or dusts, use explosionproof ventilation equipment regardless of the concentration of explosive substances.

- For odor removal in bathrooms.

REFERENCES

ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating, and Air-conditioning Engineers. Atlanta, Ga., 1985.

NAVFAC DM-3, *Mechanical Engineering*, Department of the Navy, Naval Facilities Engineering Command, Washington, D.C., September 1972.

CHAPTER 14

AIR CONDITIONING AND REFRIGERATION

Learning Objective: Identify the technical factors involved in the selection, installation, and maintenance of air-conditioning and refrigeration systems.

As a First Class or Chief Utilitiesman, you will be expected to know technical information about the air conditioning of buildings and the refrigeration of perishable products. This chapter covers the aspects of selecting and installing air-conditioning and refrigeration equipment. The individual components required in an air-conditioning and a refrigeration system are also discussed. Finally, the fundamental electrical knowledge you need to actually install, maintain, and repair air-conditioning and refrigeration equipment is discussed.

SELECTION AND INSTALLATION OF AN AIR-CONDITIONING SYSTEM

There are two types of air-conditioning systems that must be considered before selection and installation of the equipment. The first system discussed is forced air. Then, in turn, the hot and chilled water system is discussed.

FORCED AIR

Forced air units are used when the areas to be air-conditioned are in close proximity to each other, are being used for similar purposes, or have the same humidity and comfort zone requirements. A few examples are office spaces, single-dwelling homes, and single-purpose shops. Some characteristics of the system that must be taken into consideration during the planning phase are that the unit be centrally located, that it draw return air from the area being cooled, and that it be controlled by one thermostat. See figure 14-1 for two examples of a forced air unit with accompanying duct work.

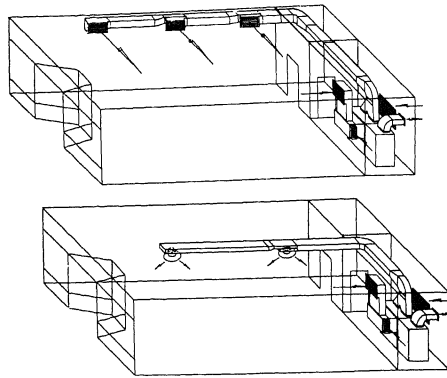
HOT AND CHILLED WATER

Hot and chilled water units should be used when the areas to be air-conditioned are dispersed, have a wide range of different uses, or have different humidity and comfort zone requirements. Some examples are a barracks, a galley, or a hospital. Some characteristics of these air-conditioning units that must be taken into consideration regarding this system are location (mechanical room), use or non-use of return air (hospital operating room), humidity and temperature controls, individual room temperature requirements, and amount of installation space for piping or ducts. See figure 14-2 for a typical piping diagram of a year-round air-conditioning system.

If you are involved in designing an air-conditioning system or desire more information, refer to NAVFAC DM 3.3, *Heating, Ventilating, Air-Conditioning and Dehumidifying Systems*.

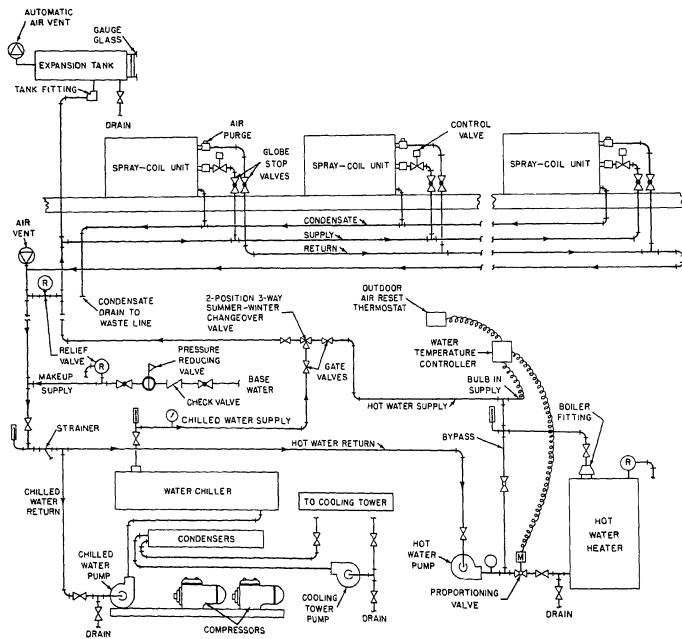
HEAT LOAD CALCULATIONS AND AIR MOVEMENT

Once the type of air-conditioning system has been chosen, the next step is to determine its appropriate size. There are two primary factors that must be considered. The first factor is heat load calculations. Humidity, comfort temperature, and psychometrics are the three primary considerations necessary for calculating the heat load. The second factor is air movement. Velocity, pressure, and drafts are the three main factors that are important when you are designing and planning the size



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Figure 14-1.—Arrangements for package-type air-conditioning units and air ducts.



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Figure 14-2.—Typical piping connections for a year-round air-conditioning system.

of an installation. Figure 14-3 shows the relationship between humidity, temperature, and air movement.

At this time, you may find it helpful to review chapter 20 on "Air Conditioning" in *Utilitiesman 3 & 2*, NAVEDTRA 10661. Additionally, the *ASHRAE Handbook of Fundamentals* is an excellent source of information.

SELECTION AND INSTALLATION OF REFRIGERATION SYSTEMS

In a refrigeration system, the major consideration is the heat load calculation. There are five

general factors that affect the refrigeration estimate required for a particular application.

- Heat leakage factor (K factor). This leakage occurs around doors and seals.
- Insulation factor (R factor). This is determined by type and thickness of the insulating material.
- Air change load. This factor is determined by the frequency with which a door is opened and closed, and the length of time a door is left open.
- Product load factor. This is determined by the types of products being stored and product temperature at time of storage.

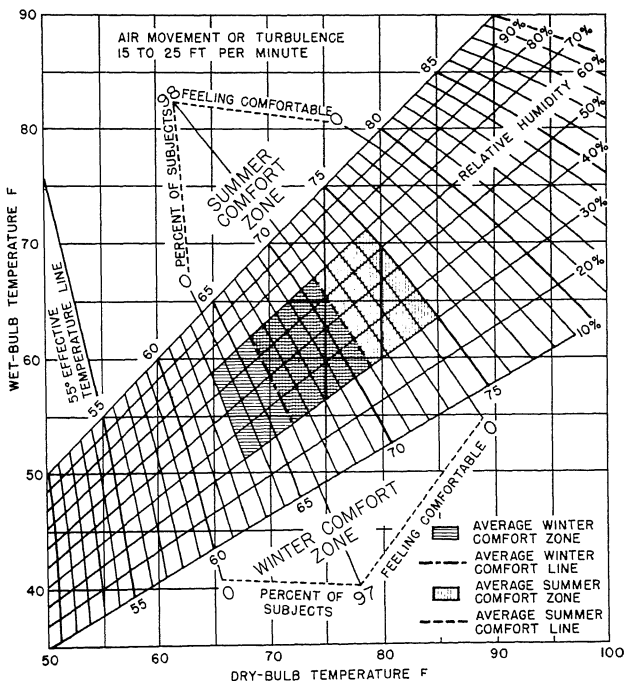


Figure 14-3.—Comfort zone chart.

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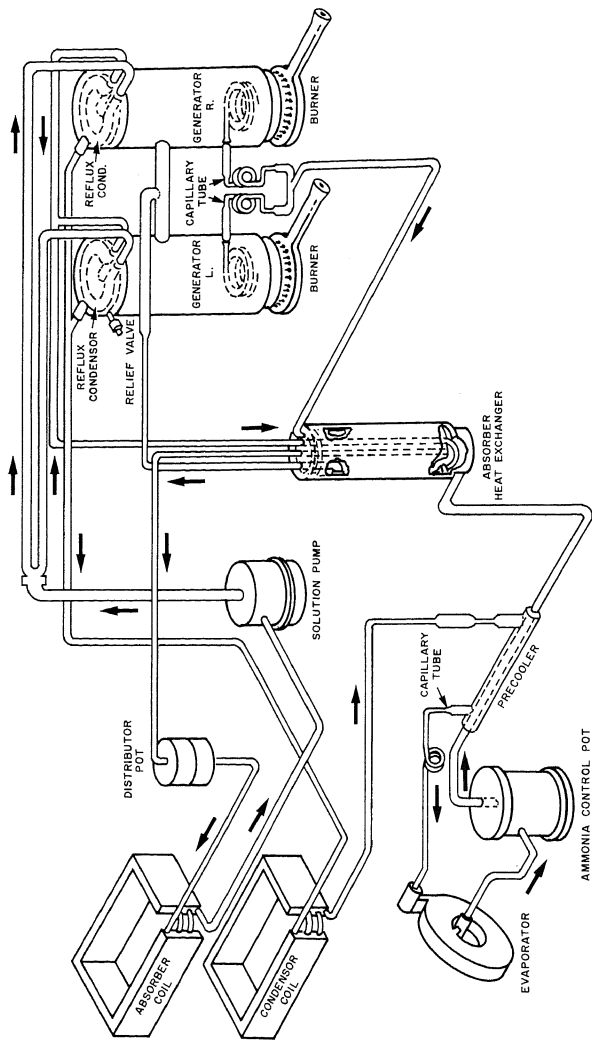


Figure 14-4.—Absorption refrigeration cycle.

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- Miscellaneous factor. This includes such factors as exposure to direct sunlight and ambient temperature surrounding the system.

There are several charts and graphs available that depict the relationship between the factors listed above. To do the job right, you must take into consideration the total effect of the factors before selecting a particular refrigeration system.

SPECIAL TYPES OF REFRIGERATION SYSTEMS

There are certain applications where an electrically powered refrigeration system cannot be used. This requires knowledge of special application and selection of a refrigeration system that will work effectively. The absorption and the expandable refrigeration systems are discussed in this section.

ABSORPTION REFRIGERATION SYSTEM

An absorption system uses either water, ammonia, or lithium bromide as the refrigerant. The system can range from very simple (small refrigerator) to complex (commercial freezer). This type of system is used in domestic and industrial refrigeration and air-conditioning applications. The absorption system is also used in recreational vehicles. Normally, these systems are identified by the type of heat source being used to power them such as kerosene, natural gas, steam, or electricity. Because of the high pressure (400 psi), you should remember that welded steel tube construction must be used throughout the system. Also, because of the reaction between ammonia and copper or brass, you need a set of steel manifold gauges. Figure 14-4 shows an absorption refrigeration cycle using ammonia as the refrigerant.

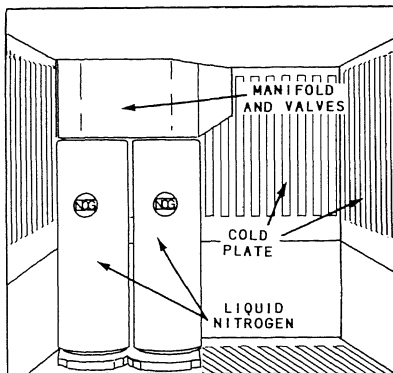
EXPANDABLE REFRIGERATION SYSTEM

An expandable refrigeration system is for use in trucks, railroad cars, and shipping containers that transport perishable items. The three types of refrigerants presently being used in an expandable system are ammonia, carbon dioxide, and nitrogen. The evaporator system and the spray system are two types of expandable systems commonly used in the Navy, and they are discussed in this section.

Evaporator Systems

In the expandable evaporator system, liquid refrigerant is stored in large metal insulated cylinders. These cylinders are normally located in the front of the cargo vehicle. Each cylinder is equipped with a temperature control to provide a temperature range of -20°F to 60°F.

The temperature control is connected to a temperature sensor. As the temperature rises, the switch operating the control valve opens and liquid refrigerant flows into the evaporator. The evaporator can be blower coils, plates, or eutectic plates. As it passes through the evaporator, the refrigerant vaporizes. This vapor is pushed through the evaporator by the pressure difference between the cylinder and the vent. When the selected temperature is attained, the refrigerant valve closes. The vapor that has been used is then discharged from the evaporator at about the same temperature as the air in the cargo vehicle. With this system, the refrigerant does not mix with air in the vehicle space. An example of the expendable evaporator system is shown in figure 14-5. This example shows two nitrogen cylinders located inside a truck body that are connected by a manifold to regulators and to temperature control solenoid valves. The vaporizing liquid nitrogen flows into the vaporizers or cold plates to refrigerate the truck box.



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Figure 14-5.—Expendable evaporator refrigeration system.

Spray System

In the expandable refrigerant spray system, liquid nitrogen or carbon dioxide is sprayed directly into the vehicle space that is to be cooled. This system uses liquid containers, a control box, a fill box, spray headers, emergency switches, and safety vents.

The fill box is normally located on the front of the vehicle. It contains the valves, gauges, and connections that allow the liquid containers to be filled. The liquid containers are insulated cylinders similar to thermos bottles. The control box contains the valves, gauges, and thermostats that are necessary for safe release of the liquid to the spray headers. Once the liquid is received at the spray headers, the nozzles spray it into the vehicle. The remaining two components are primarily safety devices. These emergency interlock switches are attached to each door. Thus, whenever a door is opened the system shuts down. The safety vent is a small trapdoor that vents air directly to the atmosphere whenever the air inside the truck box exceeds atmospheric pressure.

A benefit of this system is that liquid nitrogen or carbon dioxide replaces the oxygen inside the space being refrigerated. Therefore, when fruits, vegetables, meats, and fish are being refrigerated, they are also preserved by the inert atmosphere.

A vehicle equipped with this type of system must display the following safety sign:

CAUTION: THE TEMPERATURE OF LIQUID NITROGEN, AS IT COMES FROM THE SPRAY NOZZLES, IS BELOW 0°F.

Liquid nitrogen will instantly freeze any part of the human body that it touches. Since liquid nitrogen can be dangerous, you should always inspect the refrigerated space before closing the doors. An expandable spray system for a refrigeration truck is shown in figure 14-6. In this system, the liquid nitrogen is in an insulated container that is installed vertically inside the truck body. Another similar type of spray system with the refrigerant container mounted horizontally under the truck body is shown in figure 14-7.

THERMOELECTRIC REFRIGERATION SYSTEM

This type of system is used to move heat from one area to another by use of electrical energy. The electrical energy rather than the refrigerant

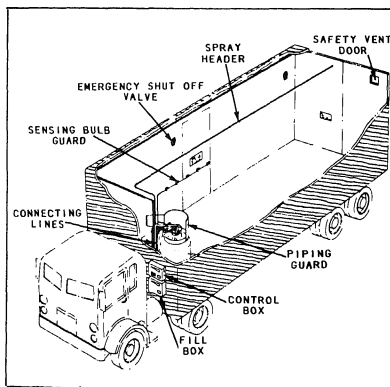
serves as a "carrier." The primary use of thermoelectric systems has been in portable refrigerators, water coolers, cooling of scientific apparatus used in space exploration, and in aircraft. The main advantage of this system is there are no moving parts. The system is compact, quiet, and requires little service.

MULTISTAGE REFRIGERATION SYSTEM

Multistage refrigeration systems are used where ultralow temperatures are required but cannot be obtained economically through the use of a single-stage system. The reason for this is the compression ratios are too high to attain the temperatures required to evaporate and condense the vapor. There are two general types of systems, presently in use—cascade and multistage (compound).

Cascade System

The cascade system has two separate refrigerant systems interconnected in such a way that the evaporator from the first unit cools the condenser of the second unit. This allows one of the units to be operated at a lower temperature and pressure than would otherwise be possible with the same type and size of single-stage system. It also allows two different refrigerants to be used, and it can produce temperatures as low as -250°F . Refer to figure 14-8. In this typical cascade system,



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Figure 14-6.—An expendable spray system.

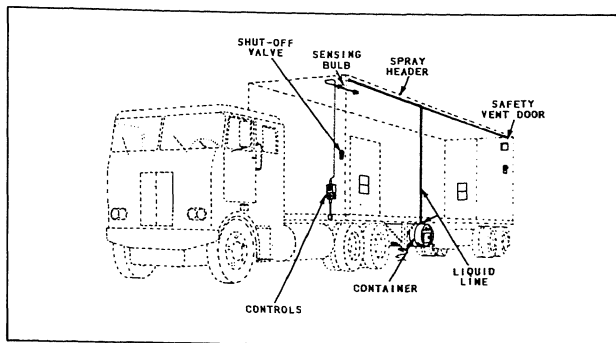


Figure 14-7.—An expendable spray system.

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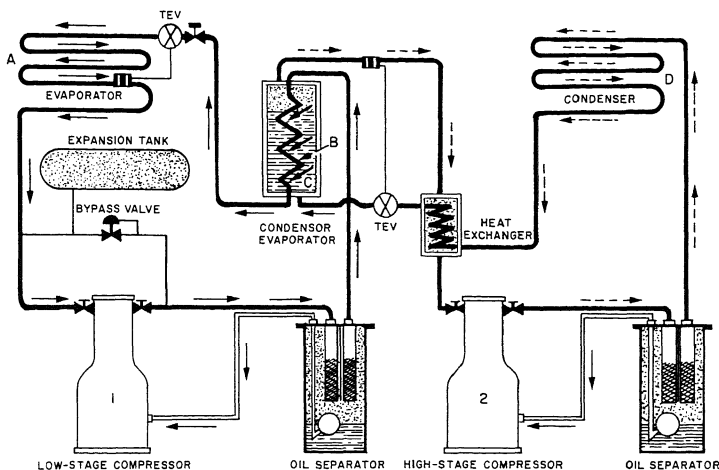


Figure 14-8.—Cascade refrigeration system.

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condenser B of system 1 is being cooled by evaporator C of system 2. This arrangement enables ultralow temperatures in evaporator A of system 1. The condenser of system 2 is shown at point D in the figure. Two TEV refrigerant controls are also indicated in the figure. Notice the use of oil separators to minimize the circulation of oil.

Compound System

The compound system uses two or more compressors connected in series in the same refrigeration system. In this type of system the first stage compressor is the largest and for each succeeding stage the compressor gets smaller. This is because

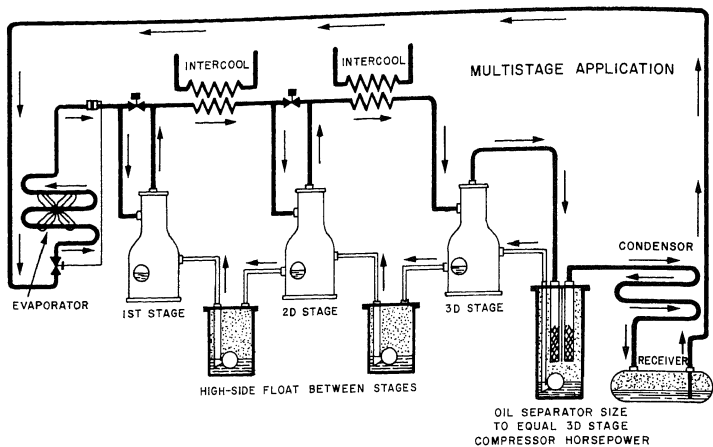


Figure 14-9.—Multistage refrigerating system.

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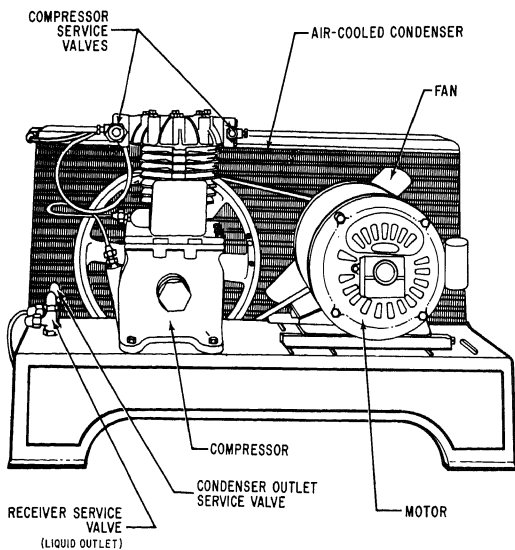


Figure 14-10.—Air-cooled condenser mounted on a compressor unit.

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as the refrigerant passes through each compressor it becomes a more dense vapor. A two-stage compound system can attain a temperature of approximately -80°F . Refer to figure 14-9. In this three-stage system a temperature of -135°F can be attained efficiently. Compressor 1 pumps vapor into the intercooler and then into the intake of compressor 2. This same operation is repeated between the second and third stages. In the third stage, the refrigerant vapor is further cooled and travels to the evaporator for specific cooling use.

MECHANICAL COMPONENT SELECTION

There are several mechanical components required in a refrigeration system. In this section some of the more common components and their selection are discussed. These components include condensers, evaporators, compressors, refrigerant lines and piping, refrigerant capacity controls, receivers, and accumulators. Many of these units and components are discussed thoroughly in *Utilitiesman 3 & 2*, NAVEDTRA 10661, chapter 19. Now is an excellent time for you to review this material. Then, proceed to read the remainder of this chapter.

CONDENSERS

There are a number of condensers to be considered when making a selection for installation. They are air-cooled, water-cooled, shell and tube, shell and coil, tube within a tube, and evaporative condensers. Each type of condenser has its own unique application. Some determining factors include size and weight of unit, weather conditions, location (city or rural), availability of electricity, and availability of water. For example, is electricity available in single phase or three phase? Is electricity economical or prohibitive? Water in some locations may be scarce, expensive, or contain chemicals that make it unsuitable for use. Local zoning laws should also be checked to ensure there are no restrictions as to use of electricity, water, or location of the unit. If the unit is to be installed on a roof, the roof load strength is of critical importance. In some locations, the noise factor of an operating unit is an important consideration. With the rapid advances in technology, you should contact a manufacturer whenever possible to get the latest condenser design features available for a special-purpose installation. A typical installation of an air-cooled condenser mounted on a compressor unit is shown in figure 14-10. Figure 14-11 shows a cutaway view of a water-cooled condenser.

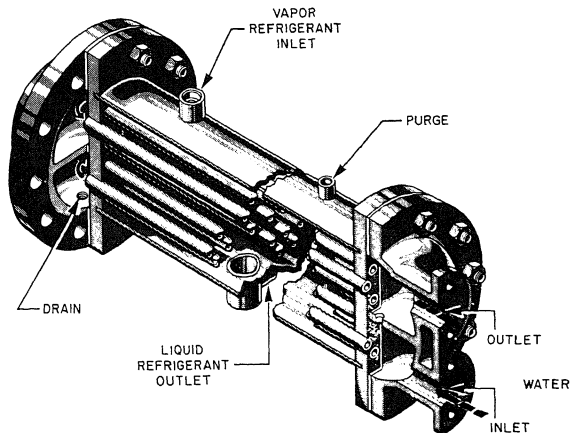


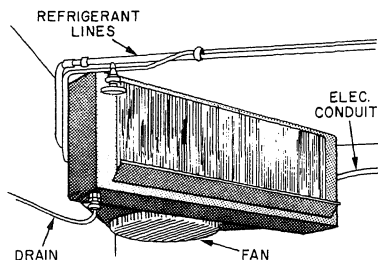
Figure 14-11.—Water-cooled condenser.

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EVAPORATORS

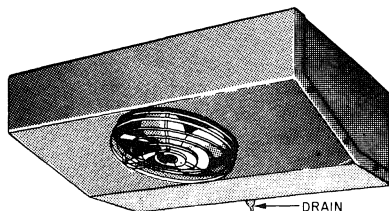
There are almost as many different types of evaporators as there are applications. However, evaporators are divided into two general groups. The first group has evaporators that cool air that, in turn, cools the product. The second group has evaporators that cool a liquid such as brine solution that, in turn, cools the product. Normally, the proper evaporator comes with the unit (system) that you will be installing. However, there may be an occasion when you are designing a system. At this time, you will need to determine the

requirements and select the proper evaporator from a manufacturer's catalog or manual. In figure 14-12 a blower-type evaporator is shown in a small space. The air enters the bottom of the evaporator, is cooled, and exits at the front of the unit. In figure 14-13, view A, a forced circulation evaporator is shown partially installed; view B shows the unit with the fan removed. A compact blower evaporator for use in low headroom fixtures is shown in figure 14-14. A vertical, flat-type blower evaporator designed for mounting behind either a window or a door frame is shown in figure 14-15. In the evaporator



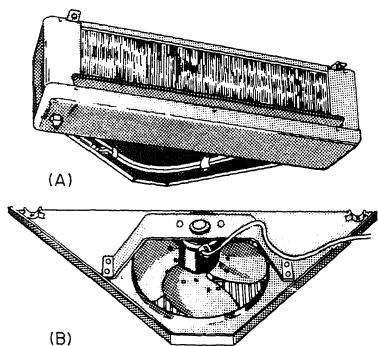
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Figure 14-12.—Blower-type evaporator.



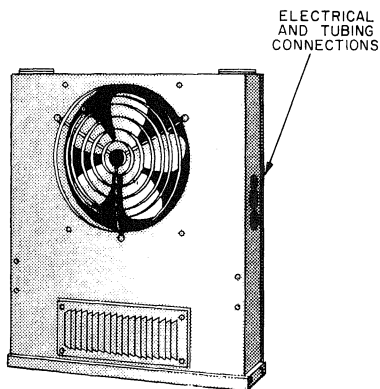
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Figure 14-14.—Compact blower evaporator.



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Figure 14-13.—(A) Forced circulation evaporator partially installed; (B) fan unit removed.



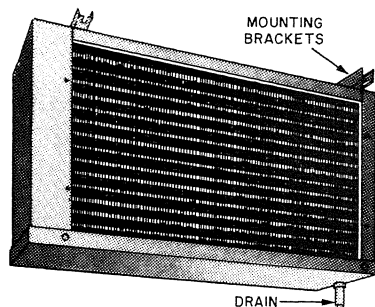
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Figure 14-15.—Vertical, flat-type blower evaporator.

unit shown in figure 14-16, the motor drives two propeller-type fans and the cooler air exits at both ends of the evaporator. Figure 14-17 shows a low-velocity blower evaporator. In this type of evaporator the air enters at the two fan grills and exits on both sides. In figure 14-18 a low-temperature blower evaporator is shown. This unit has two axial-flow fans and is equipped with electric defrost.

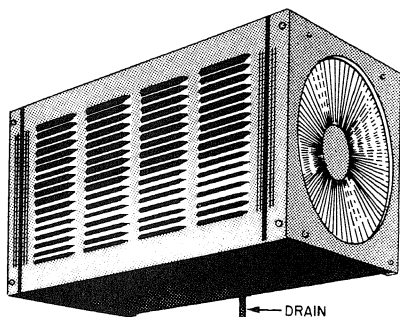
COMPRESSORS

With present technology, the newer air-conditioning and refrigeration systems are equipped with hermetic units. There are numerous models and designs of hermetic units available for all types of applications up to 20 horsepower. A typical nonaccessible hermetic compressor is shown in figure 14-19. In



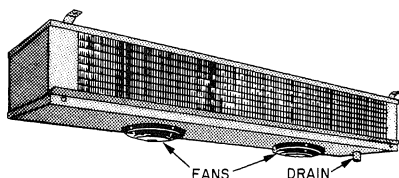
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Figure 14-18.—Low-temperature blower evaporator.



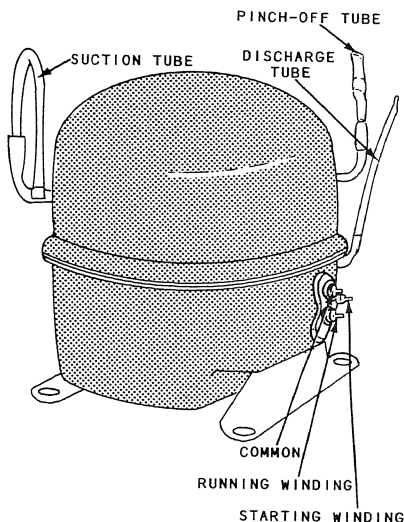
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Figure 14-16.—Dual fan evaporator.



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Figure 14-17.—Low-velocity blower evaporator.



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Figure 14-19.—Hermetic compressor.

figure 14-20, a cutaway view of a hermetic compressor motor is shown.

REFRIGERANT LINES AND PIPING

Because of the progress made in this field, construction has become much simpler. Since precharged lines are in everyday use, the problems of installation are being eliminated. However, pay

particular attention to neatness and cleanliness when you are installing support brackets (hangers) and insulation.

Figure 14-21 shows a schematic piping diagram of a typical commercial refrigeration system. This system has a roof-mounted air-cooled condenser and two motor compressors. Each motor compressor has a suction and a liquid header and is connected to six

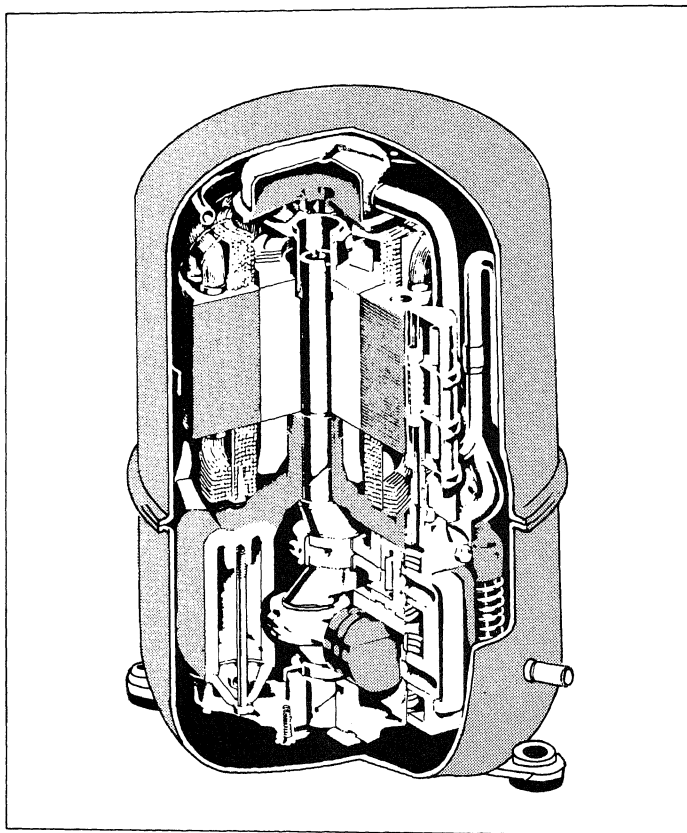
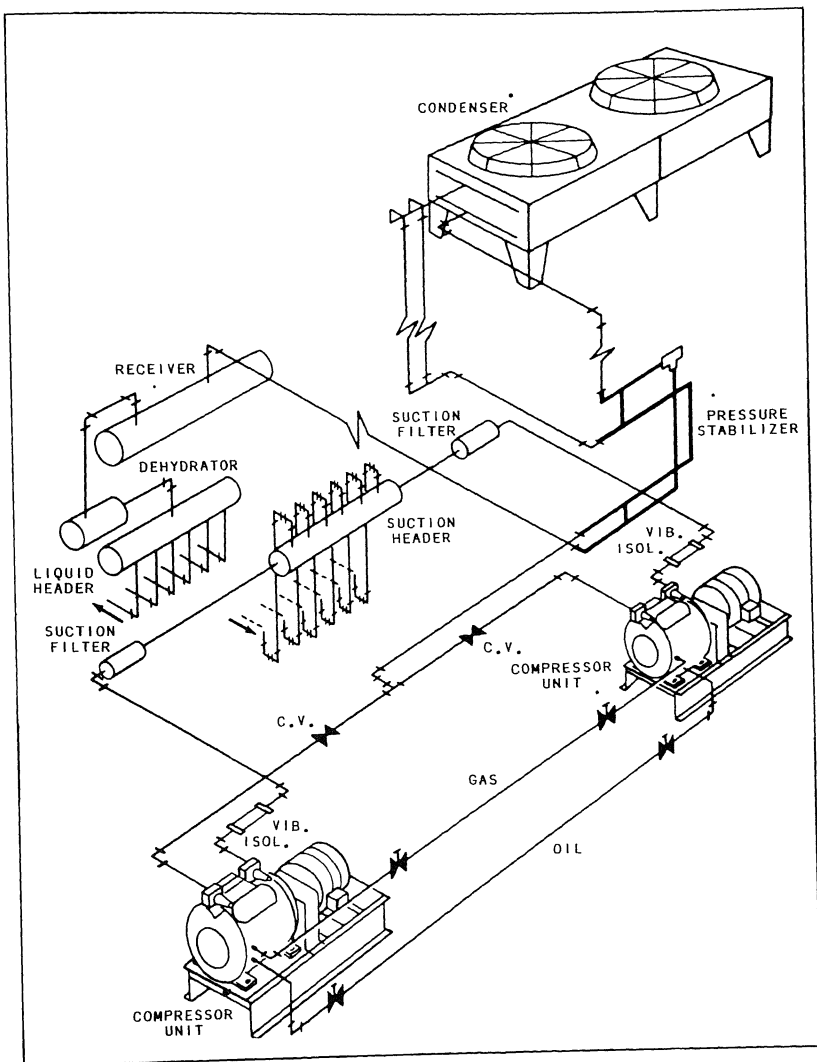


Figure 14-20.—Hermetic compressor motor.

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Figure 14-21.—Schematic piping diagram for a commercial refrigeration system.

refrigerant lines. A detailed view of an oil separator installation is shown in figure 14-22.

REFRIGERANT CAPACITY CONTROLS

In a single-stage installation, one evaporator, one condensing unit, and any one of the five types of refrigerant controls will work. However, in a multistage installation (fig. 14-9) with one condenser, only two types of controls can be used. There are very few low-side float systems in actual operation, but you should be aware that there are some units that still use this control. Thermostatic expansion valves are the most commonly used, and on large capacity units, they usually operate a pilot valve which, in turn, operates a larger valve.

The biggest problem associated with capacity controls is using one of the wrong size. When ordering replacements and when making repairs,

you should always ensure that the control markings are appropriate for the size system they are intended to be used in. Also, ensure the replacement part being ordered is compatible with the type of refrigerant being used in the system.

RECEIVERS AND ACCUMULATORS

The receiver is a storage tank for liquid refrigerant. When a refrigeration system is equipped with a receiver, you can close the outlet valve and pump refrigerant into it. This enables you to save the refrigerant while you work on the unit. Additionally, when a unit is equipped with a receiver, the quantity of refrigerant in the system is less critical than a unit not so equipped. Figure 14-23 shows the location of a receiver installed in a system. This is a commercial system with an air-cooled condenser, a thermostatic expansion valve, and a V-type compressor.

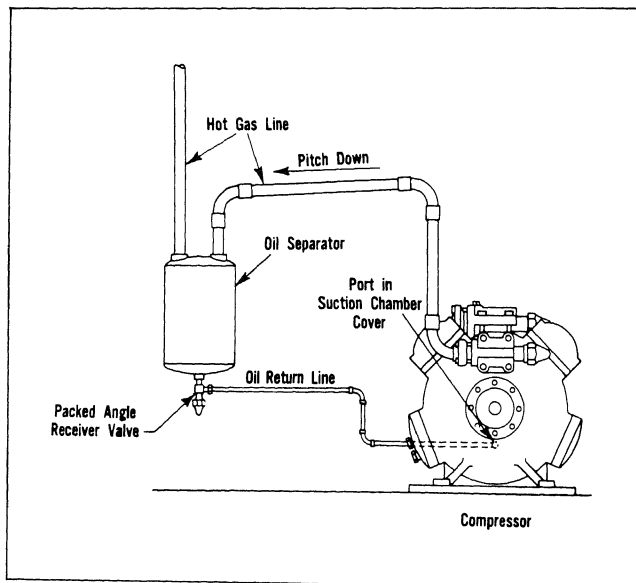


Figure 14-22.—Installation of an oil separator.

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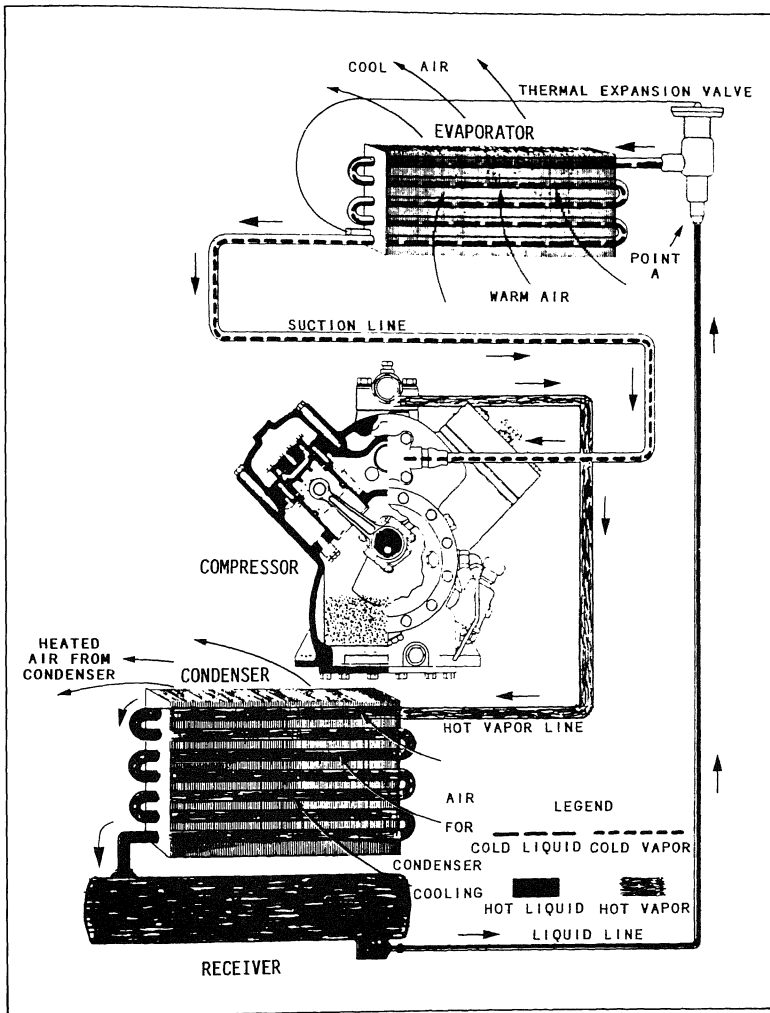


Figure 14-23.—Receiver in refrigeration cycle.

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The accumulator is located inside the refrigeration cabinet and acts as a safety device. As a safety device it prevents the flow of liquid refrigerant into the suction line and the compressor. This is because liquid refrigerant causes considerable knocking and damage to the compressor. Figure 14-24 shows the location of an accumulator in a system.

SINGLE-PHASE HERMETIC MOTORS

Basically, there are four types of single-phase motors used in hermetic assemblies: the split-phase; the capacitor-start, induction-run; the capacitor-start, capacitor-run; and the permanent split-phase. Each motor is discussed in this section.

SPLIT-PHASE

The split-phase motor is used generally on condensing units of 1/10-, 1/6-, and 1/4-horsepower

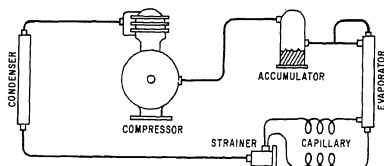


Figure 14-24.—Accumulator location.

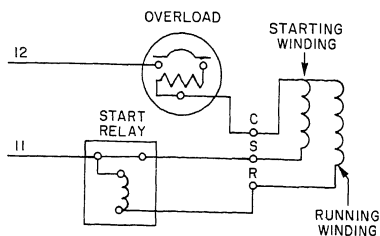


Figure 14-25.—Schematic wiring diagram of a split-phase motor circuit.

capillary tube systems. It has a low starting torque and contains both a starting winding and a running winding. A disconnect device is required for the starting winding when the motor reaches sufficient speed to operate on the running winding. Figure 14-25 is a schematic wiring diagram of a split-phase motor circuit.

CAPACITOR-START, INDUCTION-RUN

This motor is similar to the split-phase type except that a starting capacitor is connected in series with the starting winding to provide higher starting torque. Figure 14-26 is a schematic diagram illustrating this type of motor. A device is also required to disconnect the starting winding when the motor reaches rated speed. This motor is commonly used on commercial systems up to three-fourths horsepower.

CAPACITOR-START, CAPACITOR-RUN

Two capacitors are used with the capacitor-start, capacitor-run motor: a starting capacitor and a running capacitor. The capacitors are in parallel with each other and in series with the starting winding. Figure 14-27 is a schematic diagram illustrating this type of motor circuit. The two capacitors turn the motor power surges into two-phase power when the motor is started. At approximately two-thirds rated speed, the starting capacitor part of the circuit is disconnected by a start relay device. Only the running capacitor remains in the circuit. This type of motor has a

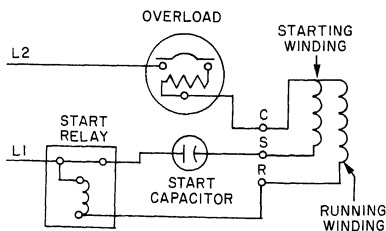
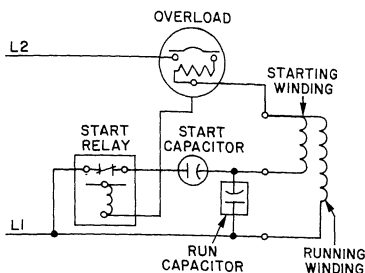


Figure 14-26.—Schematic wiring diagram of a capacitor-start induction-run motor.



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Figure 14-27.—Schematic wiring diagram of a capacitor-start capacitor-run motor.

high starting torque and is used with hermetic systems up to 5 horsepower.

PERMANENT SPLIT-PHASE

The permanent split-phase motor has limited starting torque and is used basically with capillary tube air-conditioning equipment such as window units. Capillary systems permit high-side and low-side pressure equilization when the compressor is not operating. A run capacitor is wired in series with the starting winding. Both the starting winding and the run capacitor remain in the circuit during operation. No starting relay or start capacitor is needed. Figure 14-28 is a schematic wiring diagram of the circuit used in this type of motor.

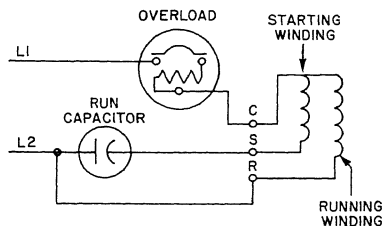
SINGLE-PHASE HERMETIC MOTOR WINDINGS AND TERMINALS

Single-phase motors used in hermetic refrigeration and air-conditioning applications are designed to start under load. These split-phase and capacitor motors use two sets of spiral windings: a starting winding and a running winding. The two sets of windings differ in their impedance and in their position in the stator slots.

The starting winding has a high resistance and a small reactance; whereas the running winding has a low resistance and a high reactance. Reactance is the opposition offered to the flow of an alternating current by the inductance and capacitance. The running winding is made up of many turns of large wire and is placed in the bottom of the stator slots. The starting winding

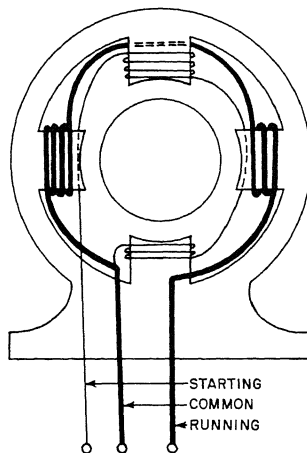
is wound of small, high-resistance wire and is placed on top of the running winding. Both windings are connected internally at one end to provide a common lead, and when starting, both are energized in parallel. The currents are out of phase with each other and their combined efforts produce a rotating field that starts the motor.

Figure 14-29 illustrates the starting and running windings of a two-pole motor in their 90-degree out-of-phase positions.



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Figure 14-28.—Schematic wiring diagram of a permanent split-phase motor.



87.243

Figure 14-29.—View of a two-pole motor having starting and running windings.

Hermetic motors have three electrical terminals connected through an insulated seal to the motor windings inside the dome. Refer to figure 14-30. Troubleshooting procedures require that these terminals be identified with respect to the winding connected to each. The terminals must be identified as the **START TERMINAL**, the **RUN TERMINAL**, and the **COMMON TERMINAL**. Some manufacturers mark the terminals S, R, and C for start, run, and common, respectively; other manufacturers use different designations.

The terminals can always be identified by using a low-range ohmmeter following the procedure below:

- Disconnect all power to the terminals, discharge capacitors where necessary, remove the wires connected to the terminals, and mark the wires so they can be reconnected properly.
- Clean terminals to provide a good connection.
- Using the ohmmeter, find the two terminals across which the greatest resistance occurs. The remaining terminal is the C-terminal. The resistance between the S- and R-terminals is

highest because both are being measured in a series circuit.

- Identify the S-terminal by placing one meter lead on the C-terminal and then checking the other two terminals to determine which one has the greatest resistance. The S-terminal (starting winding) is wound with many turns of small wire, and therefore has the greatest resistance. The remaining terminal is the connection of the running winding.

- Always mark the terminals so they can be identified later.

TESTING MOTOR WINDINGS

If, during the procedure for identifying motor terminals, the ohmmeter needle fails to move in any one of the tests, there is probably a defective winding. A defective winding may be classified as an **OPEN WINDING**, a **SHORTED WINDING**, or a **GROUND WINDING**. Test equipment and procedures applicable to faulty windings are discussed below.

OPEN WINDINGS

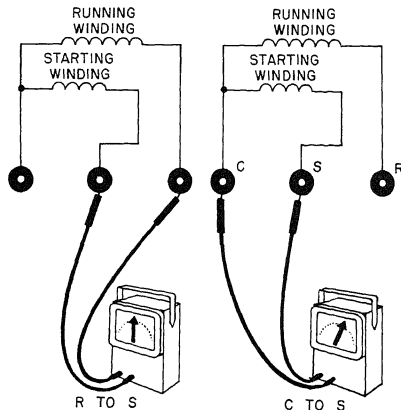
Open windings can occur in the starting winding, the running winding, or both. An open winding is the result of a burned-out or grounded fault, or simply a break somewhere in the lead or winding that prevents the current from completing the circuit. A motor with an open winding does not start. If only one winding is open, the motor hums, but if both windings are open, no sound is emitted nor current consumed. Open windings can be checked by the use of an ohmmeter, a voltmeter, or a test light.

Ohmmeter Continuity Test Procedure

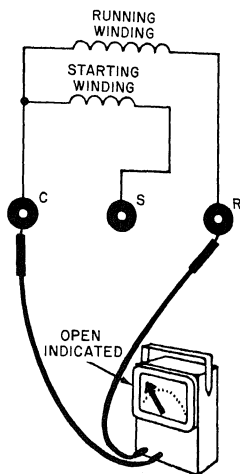
The procedure for making an ohmmeter continuity test is shown in figure 14-31 and outlined below.

- Turn off the power, discharge any capacitors, and remove the wires from the motor's C-, S-, and R-terminals.

- With the ohmmeter set on the 0- to 1000-ohm scale, check the resistance from C to R, C to S, and R to S.



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Figure 14-30.—Identifying motor terminals using an ohmmeter.



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Figure 14-31.—Testing for an open winding with an ohmmeter.

- Watch the needle on the meter as the check is made. Each reading should appear to be approximately 0 ohms, since winding resistances are usually less than 10 ohms. If, during the check, the resistance remains at 1000 ohms (infinity), an open or break exists.

Voltmeter Test Procedure

The procedure for carrying out a voltmeter test is as follows:

- Ensure the power is on and all wires are properly connected to motor terminals.
- With the voltmeter set on the proper scale, place the leads across the R- and C-terminals.
- Read the voltmeter. If the motor shows line voltage, both the starting winding and the running winding are out. The connections are similar to that illustrated in figure 14-31.

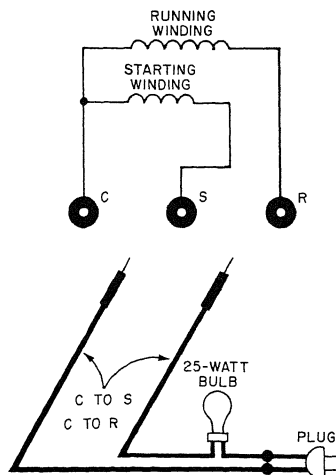
Test Lamp Continuity Check Procedure

In making a test lamp continuity check, here is the procedure to follow:

- A simple test lamp consisting of a power circuit plug, two flexible insulated wires with clip leads, and a 25-watt socket with a bulb is used. Figure 14-32 illustrates the test lamp procedure.
- Ensure the power is off, discharge any capacitors, and remove the motor terminal wires.
- Make a continuity test through both windings by attaching clips across the C-terminal, the other terminals one at a time, and then plug the test lamp into a receptacle. If the light fails to illuminate, there is an open winding.

SHORTED WINDINGS

In an electric motor the winding turns lie side by side with only the insulating varnish separating one loop from another. When one loop of the copper wire comes in contact with another, the



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Figure 14-32.—Testing for an open winding with a test lamp.

winding is shorted. The pulling effect of the shorted portion of the winding is lost. This, in turn, places more load on the active winding, causing the motor to draw higher voltage and amperage with a concurrent increase in winding temperature. In this condition the motor either fails to start, or it starts and continues to run, finally causing the overload protector to open. The fuses may blow also. The result is likely to be a burnout where the insulating varnish deteriorates from excessive heat. Ultimately a ground or short occurs.

An ohmmeter can be used to check windings for shorts. For most applications a low range meter with a scale graduated in tenths of ohms between 0 and 2 ohms is best. However, to check motors throughout the sizes normally encountered in hermetic motor-compressor units, a range of 0 to 25 ohms is necessary. The meter is used to measure resistances of the windings. The readings are compared with design resistances. A short is indicated when measured resistance is less than design resistance. The ohmmeter connections are the same as those shown in figure 14-30.

Often manufacturer's data is not available and the design resistances are not known. Table 14-1 lists the approximate resistances for fractional horsepower single-phase motors. The following guidelines may also be helpful:

1. The starting winding of low-starting torque motors usually has a resistance of about seven to eight times that of the running winding.

2. The starting winding resistance of high-starting torque motors is usually three to four times that of the running winding.

GROUNDING WINDINGS

A ground is the result of an electrical conductor in contact, either directly or indirectly, with

the motor frame or the metal shell of the unit. Either the starting winding, the running winding, or both can be affected. The ground is either one of low resistance or one of high resistance. A low-resistance ground is indicated when fuses blow repeatedly and the motor fails to start. A high-resistance ground is indicated by an occasional blown fuse, but more often by the opening of the overload protector.

Three methods of testing windings for grounds are the ohmmeter continuity test, the test lamp continuity check, and the resistance measurement with a megohmmeter. The procedure to follow in making each of these tests is given below.

Ohmmeter Continuity Test (Low-Resistance) Procedure

To perform an ohmmeter continuity test, proceed as follows:

- Disconnect the power and remove the wires from the motor terminals.
- Scrape off paint and clean a spot on the motor-compressor shell for testing.

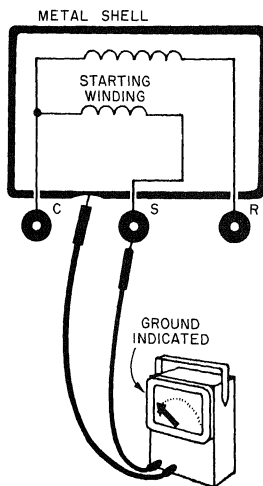


Table 14-1.—Approximate Resistances for Fractional Horsepower Motor Windings

HP	Running Winding	Starting Winding
1/8	4.7Ω	18Ω
1/6	2.7Ω	17Ω
1/5	2.3Ω	14Ω
1/4	1.7Ω	17Ω

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Figure 14-33.—Testing windings for grounds with an ohmmeter.

- With the ohmmeter set on its highest scale, test for continuity between the terminals and the shell. This procedure is shown in figure 14-33. If continuity exists between the terminals and the shell, there is a ground.

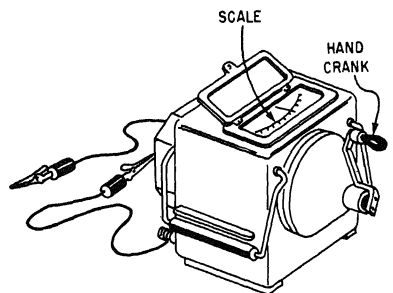
Test Lamp Continuity Check (Low-Resistance) Procedure

The procedure for conducting a test lamp continuity check is as follows:

- Disconnect the power and remove the wires from the motor terminals.
- Ensure the lamp is connected in the hot side of the line. Plug the test lamp into a receptacle.
- Connect the hot-line probe to a motor winding terminal.
- Touch the free probe to the cleaned spot on the shell. Ensure that a good connection is made. If the light illuminates, there is a grounded winding.

Megohmmeter (High-Resistance) Test Procedure

The megohmmeter (megger) consists of an indicating movement for which current is supplied by a small hand-driven generator. Figure 14-34 illustrates a typical megger used by the SEABEES.



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Figure 14-34.—A typical megohmmeter (megger).

Two leads are supplied, one of which is marked Earth or Ground.

The procedure for making the megohmmeter (high-resistance) test is as follows:

- Disconnect power and remove the wires from the motor terminals.
- Place the megger probe marked Earth or Ground on the motor or compressor frame. Ensure there is a good metal-to-metal contact.
- Place the free probe on terminals C, S, and R in sequence. If any reading of low resistance is obtained, the motor is grounded.

You should always refer to the manufacturer's instructions when using a megger. It is also a good idea to request assistance from a Construction Electrician.

ELECTRICAL CIRCUIT COMPONENTS

Electrical components in hermetic motor compressor circuits that give trouble include starting relays, overload protectors, and capacitors. It is essential that a refrigeration and air-conditioning service member be able to identify these components and test them using the proper equipment and procedures.

STARTING RELAYS

Basically there are three types of starting relays in use. They are the current relay (magnetic type), the voltage relay (magnetic type), and the thermal relay (hot-wire type). In the hermetic motor control circuit, a starting relay allows electricity to flow through the starting winding until the motor reaches two-thirds to three-fourths of its rated speed. At this time, about 3 to 4 seconds after starting, it disconnects the starting circuit.

Current Relay

A current relay is an electromagnet, similar to a solenoid valve, that employs a weight and spring to hold the contacts open when the circuit is idle. In operation the instantaneous surge of starting current actuates the magnetic coil, causing the start winding contacts to close. This closure allows starting current to the winding;

after about 3 to 4 seconds, the motor reaches its rated speed and the current decreases, causing the relay contact to open and disconnect the winding. Current relays are ideal for use with split-phase, induction-run motors.

Figure 14-35 is a schematic diagram of a current relay motor starting circuit.

Voltage Relay

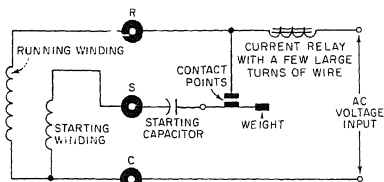
A voltage relay looks much like a current relay; however, it differs in operation. It operates on increased voltage as the motor reaches rated speed, and, unlike the current relay, the contacts remain closed during the off cycle. When the motor is first turned on, it draws heavy current and the voltage drop across the starting winding is low. As the motor picks up speed, there is less and less load; therefore, more and more voltage is induced into the winding. At about three-fourths rated speed the voltage is high enough to cause the relay coil to pull the contacts open and disconnect the winding. Voltage relays are used with

capacitor-start motors. Figure 14-36 is a schematic diagram of voltage relay motor starting circuit.

Thermal Relay

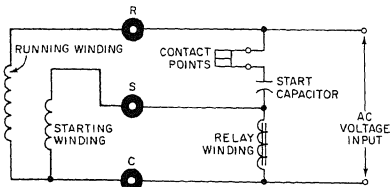
A thermal relay is commonly known as a hot-wire relay. It is available in at least two different basic designs and is supplied by several manufacturers. All thermal relays operate on the theory that electrical energy can be turned into heat energy and that, when the temperature of a metal is increased, the metal expands. Thermal relays, like current and voltage relays, operate the starting winding circuit. In addition, the thermal relay controls the running winding circuit, if for any reason the circuit draws excessive current.

The device consists of a specially calibrated wire made from a material with high oxidation resistance and two sets of contacts, all of which are integrally attached to form the relay. Figure 14-37 illustrates a typical thermal relay motor starting circuit. The contacts are controlled by the hot wire, either through the use of heat-absorbing



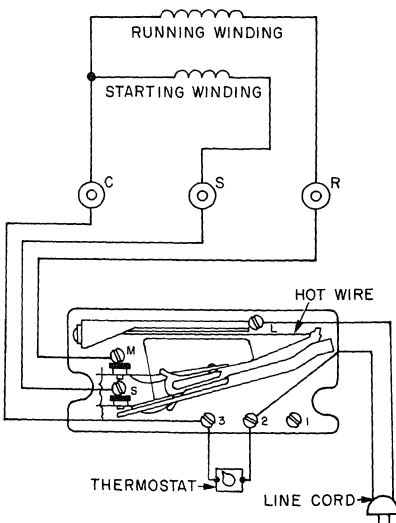
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Figure 14-35.—Schematic diagram of a current relay motor starting circuit.



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Figure 14-36.—Schematic diagram of a voltage relay motor starting circuit.



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Figure 14-37.—A typical thermal relay motor starting circuit.

bimetallic strips, or by its expansion of the hot wire, depending on the design of the relay.

OVERLOAD PROTECTORS

Essentially, an overload protector is a heat-sensitive device much like a circuit breaker. When current in the circuit increases above normal, the added current heats a bimetallic strip that bends and opens a pair of contacts. The opening of the contacts disconnects the motor running circuit and the motor stops. This prevents damage to the compressor motor when troubles occur, such as

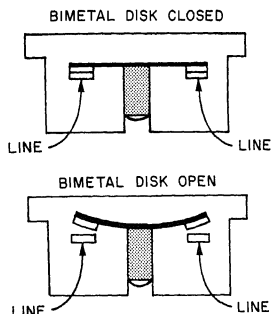
a defective starting relay, an open starting capacitor, or high head pressure. Figure 14-38 illustrates a typical bimetallic disk-type overload protector. This overload protector is connected in the common line and mounted on the compressor motor shell.

CAPACITORS

In hermetic refrigeration and air-conditioning work, capacitors are identified in two groups: starting capacitors and running capacitors. These may be identified further as dry capacitors that are used for intermittent operation, and electrolytic capacitors that are used for continuous operation. Various types of electrolytic capacitors are shown in figure 14-39.

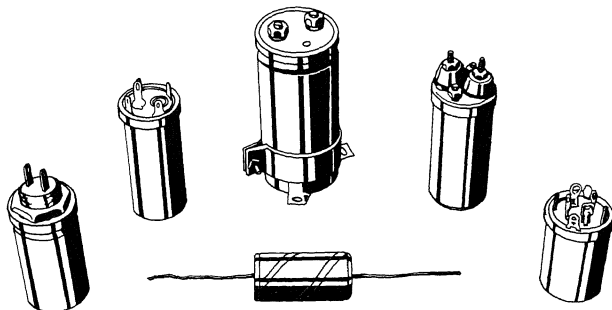
Starting capacitors are connected in series with starting windings and are usually located in the circuit between the relay and the starting winding terminal of the motor. This type of capacitor increases the initial power of the starting winding of an induction motor without increasing the amount of current used. This results in an extra surge of power to help overcome the inertia of the motor without an excessive drain on the line.

Running capacitors are connected in the circuit between the hot side of the starting and running windings. This type of capacitor serves to provide a smoother and quieter operating motor.



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Figure 14-38.—A bimetal disk-type overload protector.



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Figure 14-39.—Various types of electrolytic capacitors.

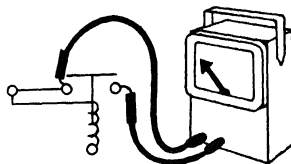
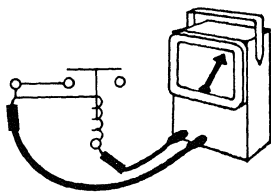


Figure 14-40.—Testing a starting relay with an ohmmeter.

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EQUIPMENT AND TEST PROCEDURES FOR ELECTRICAL CIRCUIT COMPONENTS

The equipment and procedures for testing circuit components such as starting relays, overload protectors, and capacitors are discussed as follows.

STARTING RELAYS

Starting relays can be tested two ways with an ohmmeter. The meter can be used to check across the relay contacts, or it can be used to check across the relay coil. This does not apply to thermal relays. Figure 14-40 illustrates procedures for these tests.

When you check the relay contacts, you must know if the contacts are normally open or normally closed. Voltage relay contacts and thermal relay contacts are normally closed, whereas current relay contacts are normally open. The meter reading should indicate continuity through voltage and thermal relays since the contacts are normally closed. On the other hand, if the meter indicates continuity through the normally open contacts of a current relay, the contacts are probably fused together.

Another method of checking starting relays is by using a test line cord and fuse combination to isolate the relay. Figure 14-41 illustrates the procedure used in making this test. Obtain a capacitor of the approximate size used with the compressor motor. Connect it from the hot side of the running winding to the hot side of the starting winding. Connect the test line to the motor terminals as illustrated in the figure and plug it in. If the compressor is good it should start running. After a short time, disconnect the capacitor. The compressor should continue to

speed up and run normally. This procedure has accomplished manually what a properly functioning starting relay is supposed to accomplish. If the motor failed to start normally before the check, the relay is bad.

Voltage and current relay coils can also be tested for resistance with an ohmmeter. When the coil is burned out, the meter indicates no resistance or an open coil. Commercial starting relay testers are available from several manufacturers.

OVERLOAD PROTECTORS

Questionable Klaxon external overload protectors should be replaced with new ones. If the

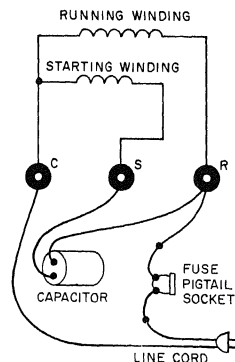


Figure 14-41.—Procedures for checking a starting relay with a test line.

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motor then operates properly, the old Klixon (protector) should be destroyed. Klixons can also be checked with an ohmmeter. Since the contacts are closed at ambient temperature, the meter should indicate continuity. When the meter indicates an open, the Klixon should be replaced and destroyed.

Internal current temperature overloads can be tested by making continuity checks. Continuity checks must be made across terminals C and S, C and R, and S and R. When both C and S and C and R show open, and continuity is indicated across S and R, the protector is open. When the temperature is normal, and the continuity test shows the overload contacts to be open, the motor compressor assembly must be replaced. When the operating temperature is normal, the internal current temperature overload contacts should be closed.

CAPACITORS

The best test for a questionable motor capacitor is to try a new one of the correct size. If the motor operates properly, the old capacitor is defective and should be destroyed.

Capacitors can also be tested with an ohmmeter. First, the power must be turned off and the capacitor discharged and disconnected. Set the meter on the 0 to 10,000 ohm scale

and touch the meter probes to the capacitor terminals. If the meter needle dips to 0 or low resistance and then climbs towards high resistance, the capacitor is good. If the needle dips to 0 or low resistance and stays there, the capacitor is shorted. If the needle does not move, the capacitor is open. Figure 14-42 illustrates these procedures.

HERMETIC ELECTRICAL SCHEMATIC WIRING DIAGRAMS

All wiring circuits are built around four requirements: a source of electrons, a place for them to flow, a path for them to follow, and a load to make use of and control the flow. The schematic wiring diagram puts the symbol and line representation on paper in a manner that allows instant identification of all four requirements. It tells the service member how and why a unit works as it does.

In the schematic wiring diagram, the source of electrons is a line drawn on one side of the diagram and it is usually designated as L1. Any and all points on this line have a surplus of electrons. On the opposite side, a line is drawn representing a shortage of electrons and it is usually designated as L2. There is a potential for electron flow between the two wires represented by L1 and L2. When a load is inserted between L1 and L2, current flows and the load functions.

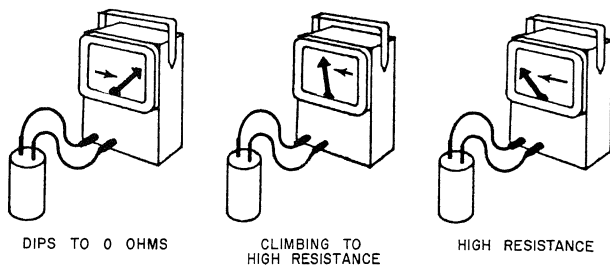


Figure 14-42.—Testing capacitors with an ohmmeter.

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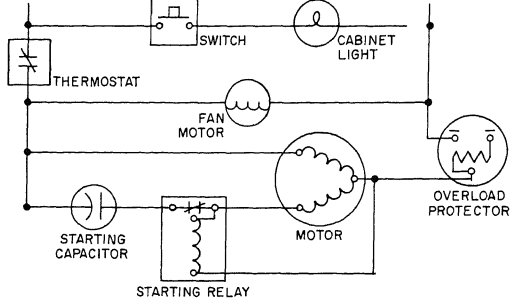


Figure 14-43.—Typical hermetic system schematic wiring diagram.

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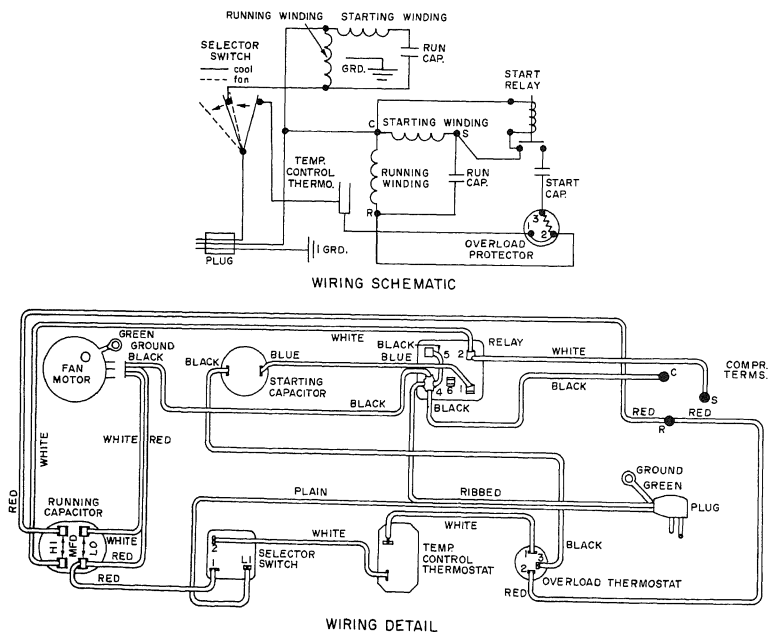


Figure 14-44.—Wiring schematic and detail for a typical room air-conditioner.

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Figure 14-43 is a typical schematic diagram for a hermetic electrical system.

There are two basic circuits. The **LOAD CIRCUIT** consists of the compressor motor, fan motor, and in general, any circuit-carrying current to a device that creates mechanical action other than the movement of an electrical switch. The second kind of circuit is the **CONTROL CIRCUIT**. This circuit consists of thermostats, pressure switches, overload protectors, or other types of electrical control devices. Figure 14-44 is a wiring schematic and a wiring detail for a typical room air-conditioner.

TROUBLESHOOTING HERMETIC ELECTRICAL SYSTEMS

General electrical troubleshooting techniques are used on hermetic refrigeration and air-conditioning equipment. Electrical troubleshooting is done by a process of elimination. You should begin by checking the most obvious trouble and gradually progress to the more remote possibilities. To be effective, you must understand the unit's electrical circuits, be aware of what the

unit is supposed to do, and then be able to recognize what it is doing. Furthermore, you must be able to identify the load and control circuits and to test them separately. It is necessary that you be able to read and interpret wiring diagrams. Practice is the best way to become an effective troubleshooter. When available, the manufacturer's instructions should be followed. This is particularly helpful when you are unfamiliar with the equipment.

Table 14-2 is a troubleshooting chart applicable to hermetic electrical systems. Problems, probable causes, and checks are listed.

REFERENCES

- Utilitiesman 3 & 2*, NAVEDTRA 10061, Volume 2, Naval Education and Training Program Development Center, Pensacola, Fla., 1983.
- ASHRAE Handbook of Fundamentals*, American Society of Heating, Refrigerating, and Air-conditioning Engineers, Atlanta, Ga., 1985.

Table 14-2.—Troubleshooting Hermetic Electrical Systems

PROBLEM	PROBABLE CAUSE	CHECK
Compressor fails to start (no sound, no hum)	No power to receptacle. Circuit breaker or fuses may be faulty	Check for power line voltage with an ac voltmeter or test lamp
	Loose wire or bad service cord	Check for continuity through plug and cord. Repair or replace if faulty
	Defective thermostat switch or loose connection in control circuit wiring	Turn off power, check all connections in the control circuit, turn thermostatic switch to coldest setting and check it for continuity. Replace the switch if it is faulty
	Open overload protector	Study the wiring diagram, use a jumper at the motor terminals or across the switch. If the motor runs the switch must be replaced
Compressor tries to start but kicks out overload (you hear the overload click)	Starting capacitor shorted or open	Replace with a suitable capacitor, and if the motor runs properly the original capacitor is defective. You may check the defective capacitor with an ohmmeter or a capacitor analyzer.
	Running capacitor shorted	Replace with a suitable capacitor, and if the motor runs properly the capacitor is defective. You may check the defective capacitor with an ohmmeter or a capacitor analyzer
	Loose wire on motor terminals or switch	Turn off power, check all connections in the control circuit, and repair if necessary
	Overload protector defective	(External) Exchange with new protector to determine if old one is defective or make a continuity check on old one. (Internal) Make continuity check across terminals C and S, C and R, and S and R to determine if the protector is open (defective) at normal temperatures

Table 14-2.—Troubleshooting Hermetic Electrical Systems—Continued

PROBLEM	PROBABLE CAUSE	CHECK
Compressor tries to start but kicks out overload (you hear the overload click)—continued	Low power line voltage	Check at circuit breaker or receptacle
	Starting relay defective	Study the wiring diagram, use a jumper across the relay, and if the motor continues to run, replace the relay
	Compressor motor shorted	Use ohmmeter procedure and test windings for a short. Compressor must be replaced if shorted
	Open winding in compressor motor (you hear motor hum)	Use test lamp, ohmmeter, or voltmeter procedure and test windings for open. Compressor must be replaced if an open exists
Compressor starts but doesn't switch from the start winding to the run winding	Low voltage	Use voltmeter to check line voltage. It should be within $\pm 10\%$ of nameplate voltage
	Starting relay fails to open	Contacts may not open due to burned surfaces. With power off, determine condition of the controls using an ohmmeter
	Run capacitor defective	A defective run capacitor would limit the amount of voltage required to open the starting relay contacts. Substitute with a capacitor and check old one with an ohmmeter
	Open motor winding	Use ohmmeter or test lamp procedure for testing windings
	Shorted motor winding	Use ohmmeter to check resistance of windings
	Improperly wired	Study the manufacturer's schematic wiring or detail diagram and compare with actual wiring

CHAPTER 15

ENVIRONMENTAL POLLUTION CONTROL

Learning Objective: Identify the techniques used in the identification, prevention, and cleanup of environmental pollutants of water, ground, and air to include the cleanup of oil spills.

Environmental pollution results from chemical, physical, or biological agents in the water, ground, or air that alter the natural environment. Pollution adversely affects human health, plant life, fish, and wildlife. Pollution can disintegrate nylon line, crumble masonry, corrode steel, and darken the skies. Most important is the damage to vegetation, human illness, and loss of productivity. The majority of pollution can be prevented, or at least slowed down, if people control the amount of foreign matter they put into the environment.

This chapter briefly covers ways to prevent water, ground, and air pollution on the jobsite. It also describes the means by which the Utilitiesman can help prevent, control, and clean up the pollution.

WATER AND GROUND POLLUTION

Other than creating a fire hazard, oil and other petroleum-related products pose many possible pollution threats when spilled in the water, dumped into the storm or sanitary sewer system, or spilled on the ground. Oil products on the ground infiltrate and contaminate surface water supplies with the groundwater runoff caused by rain. Oil products dumped or carried into storm or sanitary sewers are also potential explosion hazards.

Oily wastewater from boiler rooms, banks of walk-in refrigeration units, and motor pool operations are caused by

- improper handling and storage of new and waste oil,

- equipment and vehicle washing operations, and

- various other maintenance activities that generate liquid waste or wastewater that must be stored or treated.

An oil slick on the surface of the water blocks the flow of oxygen from the atmosphere into the water. This is harmful to fish and other aquatic life. If the fish do not die from the oil coating on their gills, or from eating the oil or oil-laden food, their flesh is tainted and they are no longer fit for human consumption. Other than harming aquatic life, drinking water can become contaminated. Drinking water from wells and surface storage facilities is treated with chemicals to rid the water of harmful bacteria. However, no amount of treatment can rid a system of contamination from waste oil products. The system must be abandoned.

As a shop supervisor, your prime concern should be to prevent oil in the shop from draining into storm sewers and surface drainage systems. During pipe threading operations, you should provide catch pans and have absorbent materials available to soak up spilled oil. Spilled oil and fuels should NEVER be washed down a drain or sewer unless an immediate fire hazard exists and an oil-water separator is connected to the discharge line. Where minor spills are expected to occur occasionally (pipe threading, boiler burner cleaning, compressor oil change), absorbent material should be sprinkled on the spill, picked up, and then placed in an EPA-approved container. The containers are normally disposed of through the Defense Property Disposal Office (DPDO). When this is not possible, the containers must be disposed of

through a government-approved contractor or in a sanitary landfill approved by local government authorities.

Waste oils, filters, and contaminated fuel should be collected and disposed of in a non-polluting manner. Most naval activities collect and dispose of waste oil periodically through a contractor who may burn it in a boiler plant, or in a heating system. The contractor may also reprocess it in an oil reclamation plant. Naval supply fuel farms usually have the means to dispose of waste oils properly.

As a senior Utilitiesman, you will see contaminated water run off the Equipment Operator's washrack every day. You should work closely with the person in charge of the washrack to ensure that this wastewater is treated and not discharged into the storm system. Provisions must be made for pretreating or separating oil products and cleaning solvents used at the washrack.

Other than preventing oil pollution from vehicle and base equipment operation, SEABEES are being considered for use in beach cleanup during major oil spill disasters. The techniques and uses of construction equipment in beach cleanup should be incorporated into SEABEE training requirements. In the event of a regional or national disaster from a major oil spill, this new manpower capability can be used very effectively by local commanders. A well-trained SEABEE team can form the nucleus of a large-scale beach cleanup exercise team by using a large number of qualified personnel and heavy equipment.

AIR POLLUTION

As a First Class or Chief Utilitiesman, you should be aware of work conditions that cause air pollution, and of the efforts required to minimize or correct the problem.

When incomplete combustion occurs in base boilers, space heaters, and stoves, the unburned hydrocarbons and various other fuel components combine chemically to form by-products. Many of these by-products are harmful when emitted into the environment.

These by-products that have an adverse effect on the air are carbon monoxide, particulate matter, sulfur oxides, unburned hydrocarbons, nitrogen oxides, and lead. The most effective means of controlling air pollution from incomplete fuel combustion is to properly and frequently maintain the equipment. In this way,

the equipment is operating at an optimal fuel and oxygen mixture. Another alternative, not always under your control, is to use only the best grade of fuel. This fuel contains low particulate matter, low water and sulfur content, and few contaminants.

ASBESTOS

Asbestos dust is another air pollutant that you must be knowledgeable of and concerned with in the installation, maintenance, and removal of asbestos material from a construction site.

Asbestos is a fibrous mineral that can be woven like wool. Through a variety of processes, asbestos can be turned into thousands of construction products. These products were used extensively from the 1930s through the 1960s. Asbestos has been used by mankind for over 2,500 years. However, it was not until the early 1800s that asbestos was found to be a health hazard. In the 1900s, only miners and people working in industrial manufacturing plants were believed to be affected by asbestos. As research continued into the 1900s, asbestos was discovered to be the main cause of asbestosis, a generic term for a wide range of asbestos-related disorders and mesothelioma. Mesothelioma at one time was a very rare form of lung cancer. It is presently occurring much more frequently among people exposed to asbestos dust particles.

There are three terms associated with asbestos dust particle size that you will encounter. These terms are micron, nanometer, and angstrom. To give you an idea of their size, in 1 meter there are 1 million microns, 1 billion nanometers, and 10 billion angstroms.

It was not until the advent of the transmission electron microscope (TEM) and the scanning electron microscope (SEM) in the latter part of the 1950s that the true size (200 to 250 angstroms) of an asbestos particle was discovered. Within this size range, air that appears to be dust free can contain millions of disease-producing asbestos particles. These minuscule asbestos particles have lead to many laws, regulations, and cleanup problems. Although these particles cannot be seen, they remain suspended in the air for months. In working to solve this problem, you must take air samples to ascertain the severity of the situation. To remove the particles, the air must be scrubbed with a special air filtration machine.

At the time of this writing, Navy guidance for asbestos use, demolition, and disposal is covered by OPNAVINST 5100.23B of 31 August 1983.

However, you should also endeavor to learn the local laws and restrictions pertinent to the locale in which you work. These federal, state, and local laws or ordinances are extremely important. In an overseas location, the laws of the host country must be researched and clearly understood in the construction planning phase. It is inevitable that somewhere in the disposal cycle, transporting of this type of material to a disposal site will take place over roads not directly under Navy control.

In all cases, you must research the laws governing asbestos. If you are continually involved with asbestos, you need to stay informed of current regulations and laws because they are constantly changing and being updated. At the present time, legislation is proposed to outlaw all forms and uses of asbestos.

PESTICIDES

There are also numerous chemicals and pesticides that release harmful and deadly fumes

into the air—for example, chlorine gas. It is important for you to become very familiar with all the materials used by shop personnel within your jurisdiction. Normally, toxic substances have warning labels affixed to them. Once the chemicals being used are identified, you can obtain supplemental information from the unit environmental protection office, or from the local safety office.

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